THE STRUCTURE OF ASIA

EDITED BY

J. W. GREGORY

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PREFACE

ASIA, as the largest of the continents, should provide the largest share of the facts of geology and from its central position it is best placed to help in their correlation. Hitherto so much of Asia has been so little known that it has contributed far less than Europe to knowledge of the mountain system and geology of the Old World. During the past thirty years much fresh information as to the structure of Asia has been provided by the Russian geologists in Siberia, the Geological Surveys and Geological Societies of China and Japan, the French geologists in Indo-China, the Dutch in the East Indies, the Geological Survey of India, and the geologists investigating the oil fields of Persia and Mesopotamia. The greatest single advance in the interpretation of the structure of Asia was the publication in 1901 of the third volume of *The Face of the Earth* by Eduard Suess of Vienna; and the time has now come when his explanations should be reconsidered in the light of the new evidence. The British Association meeting in Glasgow in September, 1928, afforded a suitable opportunity. An international discussion was held then, and the papers contributed to it have been collected in this volume.

Most of the chapters discuss previously published evidence; but that plan was unsuitable for the Persian Arc, for so much new information had been collected by

the geologists of the Anglo-Persian Oil Co., that until it were made public any discussion of that area would have been futile. By kind permission of Sir John Cadman, an account of the stratigraphical results obtained there has been contributed by Professor de Böckh, Dr. Lees, and Mr. F. D. S. Richardson. Their contribution differs in scope from the rest of the book, as it states the new evidence as well as discussing it. That chapter, owing to its new information, maps and sections, will rank as one of the primary documents on the geology of South-Western Asia.

The Anglo-Persian Oil Co. has generously given a grant which has rendered possible the publication of the maps and illustrations with the Persian chapter.

Since the book was set up in print two contributions to the subject have been issued to which reference should be made. A detailed account of the area discussed in Chapter IV is given in a memoir, D. I. Mushketov, Geological Map of Central Asia, sheets VI-7, VII-7, East Ferghana, *Mémoires du Comité Géologique*, Leningrad, new ser., livr. 169, 1928. The work summarized in Chapter V has been fully described by the Geological Survey of India in a memoir by G. E. Pilgrim and W. D. West, "The Structure and Correlation of the Simla Rocks," *Mem. Geol. Surv. India*, Vol. LIII, 1928.

J. W. GREGORY

UNIVERSITY, GLASGOW
June, 1929

CONTENTS

LIST OF PLATES

LIST OF DIAGRAMS IN THE TEXT

THE STRUCTURE OF ASIA

CHAPTER I

INTRODUCTION

By Professor J. W. Gregory, LL.D., D.Sc., F.R.S.,
Professor of Geology, University of Glasgow

The Three Primary Divisions of Asia—The Altaid System—Argand's Synthesis—Professor F. E. Suess and the Asiatic Synthesis—Turkestan and the Reversal of the Asiatic Direction—The Persian Arc—The Himalaya—Mongolia and the Gobi—Siberia and the Arc of Verkhoyansk—The Eastern Marginal Arcs—South-Eastern Asia—Conclusions.

1. The Three Primary Divisions of Asia—The relief map of Asia shows that the continent consists of three series of geographical units. The first series includes the great southern peninsulas; the second consists of a broad mountain belt that extends across the continent and expands from a width of 300 miles near the Caspian until, according to some interpretations, it occupies the whole of the eastern side of Asia; the third series consists of the northern plains, the steppes and tundras, which range from the mountain belt to the Arctic Ocean. The geological evidence as to the nature and age of the rocks in the three constituent elements of Asia confirms the impression from the relief map. Suess, in perhaps the most important volume of his all-important work, *The Face of the Earth* (Vol. III; German edition, 1901),[1]

[1] The references to Suess are given to the English edition; but the dates given are of the German edition.

advanced a synthesis of Asia based on its classification into these three primary divisions. The southern peninsulas, Arabia and the peninsular part of India, are fragments of the ancient continent of Gondwanaland. The northern plains include stable areas of ancient rocks that were worn down to a peneplane by prolonged denudation, while the belt to the S. was being upheaved by mountain movements; the ancient rocks form worn-down blocks, of which the most important is Suess' "Primitive Nucleus," the foundation of Central Siberia, as far north as the Arctic Circle, of Angara-land, Manchuria, and Mongolia. The essential constituent

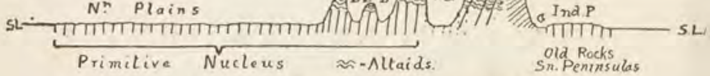


FIG. 1.—SECTION NORTH AND SOUTH ACROSS ASIA.

Diagrammatic section from the coast of Siberia to near Madras. To the north the Primitive Nucleus exists in part as the northern plains, and is in part surmounted by the Altaid Mountains. The mountain belt ends to the south with the Himalaya rising above the plain of the Ganges, with further south the Indian Peninsula.

[At. = Altyn Tag; Dz. B. = Basin of Dzungaria; G. = Ganges Valley; H. = Himalaya; Ind. P. = Indian Peninsula; K.L. = Kuen Lun; T.B. = Tarim Basin (Serindia); Tb. = Tarbagatai Range; T.S. = Tian Shan; S.L. = Sea Level.

of the fold-mountain belt is a series of parallel, sub-parallel, and crescentic ranges, which extend from Asia Minor through Persia, Tibet, China and the East Indies.

The Primitive Nucleus on the N. and the two southern peninsulas consist largely of ancient blocks with comparatively few marine rocks; but the mountain belt includes a varied series of the deposits of an ancient persistent sea, the Tethys. The buckling of the marine rocks of the Tethys into the mountain belt joined the northern nucleus and the southern peninsulas and thus formed the continent of Asia.

Many conspicuous features suggest that the mountain belt of Asia was formed by pressure from the N.; whereas the Alpine Mountains which form the main axis of Europe were

due to pressure from the S. The essential problem in the structure of Asia is the nature of the earth movements which crumpled the band between the northern nucleus and the

FIG. 2.—SKETCH MAP OF ASIA.
Showing the course of the Altaids, the Himalayan-Alpine System, and the Boundary of the Primitive Nucleus of Asia.

southern peninsular plateaus into the intervening mountain belt. The main line of the mountain belt includes the Himalaya, and branches to the S. enclose basins or embrace parts of the southern lands. The Himalaya, according to

traditional opinion, correspond in Asia to the Caucasus and the Alps in Europe; but there have been many conflicting hypotheses as to the further eastern continuation. According to Kropotkin[1] and Little,[2] the Himalayan line turns north-eastward, crosses western and Central China, passes W. of Pekin, and continues through the Khingan Mountains to the Bering Strait. Suess, with a fuller knowledge and truer appreciation of the facts, pointed out that the Khingan Mountains are essentially different from the Himalaya. According to his interpretation, the Himalayan line bends back in a horseshoe curve around Assam, turns southward through western Burma, and continues through the Malay Arc on the southern side of the Eastern Archipelago (East Indies).

2. The Altaid System—The members of the Asiatic mountain system are of very different topographic value. The Himalaya rise above India with an unbroken front, with unscaleable precipices and pinnacles, and without passes across it. Other chains are long tracks of downland which are free from crags, have gentle slopes, and are high simply because they are huge. They are big hills, rather than mountains. Suess,[3] for example, describes one of them, the Bei Shan, as "for the greater part it is a true desert traversed by long, low rocky ridges." Yet their geological structure shows that they are the roots of ancient mountains which in their prime were doubtless as lofty and craggy as the Himalaya. The differences between these two types of mountains may be due to age or original structure. The Alps and the Himalaya are geologically modern. They were not upheaved in one geological epoch any more than Rome was built in a day. They are due to a succession of movements which culminated in the Middle Kainozoic. The down-like mountains, on the other hand, are much older. Some of them consist of ancient plateau-blocks like the horsts of France and Germany, which form the Hercynian, Variscan, and Armorican Mountains.

[1] P. Kropotkin, "The Orography of Asia," *Geogr. Journ.*, Vol. XXIII (1904), p. 333.

[2] A. Little, *The Far East* (1905), p. 209, and map opp. p. 19.

[3] Suess, *Face of the Earth*, Vol. III (1901), p. 169.

Suess pointed out that the Altai Mountains of Asia correspond with the Armorican-Variscan Mountains of Europe, and not with the Alps. He traced mountains of the same character as the Altai through Asia and across Europe, through Northern Africa, and beyond the Atlantic in the eastern and central parts of the United States. He grouped these mountains into one mountain system and called them the Altaids, after their best-known representative in Asia. They take their name from the Russian Altai Mountains, and include the Tian Shan, Bei Shan, Lun Shan, Nan Shan, and Central Kuen Lun; the Ala Shan, In Shan and Tsin-ling Shan in China; the Chugoku, Shikoku and other so-called "Paleozoic Mountains" of western Japan; and the ridges that form the main axes of the East Indian islands. Suess retained the names Variscan and Armorican for European members of this Altaid System. He did not adopt Hercynian, as that name had been already used in two different senses. He followed the most convenient course when, in establishing a mountain system that ranges through four continents, he gave it a special name; and he chose the most appropriate available.[1] The names previously used may be retained for the local representatives, such as the Armorican, Variscan, Appalachian, the English Pennine, the Japanese Chugoku, etc.

According to Suess, the Altaids are the main girders in the edifice of Asia, and dominate the structure of the continent. Suess did not accept any of the Asiatic Mountains as representing the Alps of Europe; for he correlated the Himalaya with the Dinaric Mountains. He regarded the development of the Alps as moulded to so large an extent by the European Altaids that he described the Alps as "posthumous Altaids"; and he explained some of them as formed by the compression of post-Altaid rocks that had been laid down in the hollows of the Altaid framework. Suess recognized that there were in Asia mountains, such as the Sayans, near Lake Baikal, which are fragments of systems older than the Altaids; but

[1] It is open to the objection, as I have previously remarked (*Geogr. Journ.*, Vol. XLV (1915), pp. 503-4), that the Altai of Mongolia do not belong to the system. The name is taken from the Russian Altaids.

they are geographically less important, as their remains are as fragmentary compared with the Altaids as the Altaids are in comparison with the Alps.

3. ARGAND'S SYNTHESIS—Suess's descriptions of the Asiatic Mountains were in parts sketchy, for at that date the evidence regarding many of them was even more imperfect than it still remains. His classification needs reform, and in a summary of it in the *Geographical Journal* (Vol. XLV, 1915, pp. 497-509) I ventured to modify it to bring it into line with later information. In recent years Suess's classification has been set aside in a memoir by Professor Argand,[1] who represents the present structure of Asia as due to the union and contortion of various elements as the whole mass drifted southward. This southern drift he regards as the cause of the Asiatic Mountains belonging to the Alpine Cycle, in which he includes both the Altaids and the Asiatic extensions of the Alps. Suess, on the other hand, regards the Alps and their representatives in Asia as much later in date than the Altaids. Both Argand and Suess recognize great differences between the Alps and the Altaids. Suess attributed the differences to the Alps being the summits of recent, and the Altaids the roots of ancient, mountains. That explanation seems to me more satisfactory than Argand's view that the Alps are superficial broken folds (*plis de couverture*), like the breakers in surf, while the Altaids are deep-seated folds (*plis de fond*), like the waves in a ground-swell. Argand's hypothesis is that the fashion of the Alps differs from that of the Altaids owing to an original difference in structure between corresponding contemporary parts; whereas Suess considered the differences comparable to those between the roof of a modern building and the foundation of an old one. A useful comparison must be between equivalent structures.

The question is, however, not to be settled by a simple comparison of external form. Suess did not assign all the Asiatic mountains which are high and rugged to his Alpine division, nor regard all his Altaids as ancient and worn-down. His classification suffers from the defect of paying too little

[1] E. Argand, "La Tectonique de l'Asie," *Comptes Rendues, Congrès Géologique Internationale*, XIII, Brussels (1924), Vol. I, pp. 171-372.

attention to the existing characters of the mountains; and his faith in trend-lines led him to group together mountains in very different stages of preservation. Hence in my re-statement in 1915 of Suess's classification I modified it so as to give due weight to the existing form of the mountains. Professor F. E. Suess agrees in the necessity for this change (Chap. II, p. 37).

4. PROFESSOR F. E. SUESS AND THE ASIATIC SYNTHESIS—Argand's statement of his theory is not always clear, but an admirable exposition of his main principles is given in the contribution to this volume (Chap. II) by Professor F. E. Suess.[1] He abandons his father's views in two fundamental respects—the nature of the Primitive Nucleus of Asia, and the correlation of the Altaid Mountains. The Primitive Nucleus, according to Edward Suess, consisted of a mass of pre-Paleozoic crystalline schists, and it formed a firm nucleus around which the later materials have been collected and arranged. It is universally recognized that rocks may be altered into crystalline schists at any age by contact metamorphism at moderate depths, and by thermal metamorphism at great depths; but the regional areas of true crystalline schists, wherever their age is proved by contact with Cambrian or other Lower Paleozoic rocks, appear to be pre-Cambrian. Professor F. E. Suess, however, adopts the views that some of the crystalline schists of the Alps and of the Variscan horsts are of Middle or Upper Paleozoic Age, and he claims that much of the gneiss and schists in the Altaids of Europe is also Upper Paleozoic and throws doubt on the pre-Paleozoic Age of those rocks in the Primitive Nucleus of Asia. He attributes the foliation of these rocks to the intrusion of great granitic masses at the end of the Paleozoic by the phenomena which he has so well described as "intrusion-tectonics."[2]

At one time a specimen was exhibited in the Museum at Berne and described as gneiss containing Carboniferous plants; and Swiss rocks containing crushed belemnites were accepted generally as crystalline schists. The demonstration

[1] *Cf.* also F. E. Bailey, *Nature*, Vol. CXVII (1926), pp. 863-4.

[2] F. E. Suess, *Intrusionstektonik und Wandertektonik im Variszischen Grundgebirge* (1926).

by Bonney[1] that the Jurassic and Triassic rocks which have been claimed as schists are younger than the adjacent crystalline schists, fragments of which they contain, has been widely ignored and never adequately answered. The classifications of Professor Fr. Heritsch[2] and Dr. Hans Jenny,[3] who, among modern authorities, assign the "true crystalline schists" of the Alps to the pre-Paleozoic Era, appears to me more probable than the determination of various Alpine true schists as Mesozoic. That the crystalline schists in the Variscan Mountains are altered Upper Paleozoic sediments appears still unproved.[4] The once prevalent belief that the crystalline schists of the Scottish Highlands are mainly or partly altered Paleozoic rocks and were foliated by intrusions of granite has been widely abandoned. Extensive contact metamorphism has taken place on the borders of some Scottish granites; but the evidence seems to me conclusive that the Highland schists were schists before the granitic intrusions, and before the earth movements that produced the Lower Devonian thrust-planes. Apart from analogy, the pre-Cambrian age of the schists of the Altai seems proved by the superposition of the Cambrian rocks on the schists of the Primitive Nucleus and of its western border near Krasnoyarsk, and in the Altai Mountains on the Upper Obi, as well as by the superposition of Silurian and Devonian rocks on the schists in other parts of the Altai. Suess's view that the regional masses of schists and gneisses in northern Asia are part of a pre-Paleozoic coign and are the oldest known rocks in that region still seems highly probable. That conclusion is supported in this volume (pp. 207-8) by Professor Berkey, who regards the schists of the Mongolian region as pre-Cambrian.

The second fundamental principle in which Professor F. E. Suess departs from the views of Eduard Suess is by casting

[1] T. G. Bonney, "Crystalline Schists and their Relations to Mesozoic Rocks in the Lepontine Alps," *Quart. Journ. Geol. Soc.*, Vol. XLVI (1890), pp. 187-236.

[2] Fr. Heritsch, *Die Grundlagen der Alpinen Tektonik* (1923), pp. 135, 136, etc.

[3] H. Jenny, *Die Alpine Faltung* (1924), p. 100.

[4] Their Paleozoic age is rejected in the recent work by Professor S. von Bubnoff, *Der Werdegang einer Eruptivmasse* (1928), p. 220.

doubt on the correlation of the European and Asiatic Altaids. Professor F. E. Suess agrees with Professor Argand that the present structure of Asia is due to earth movements which are included in the Alpine Cycle, were begun in the Mesozoic, culminated in the Middle Kainozoic, and made the Alps in Europe and the Himalaya in Asia. These movements, according to Argand and F. E. Suess, demolished the previous structures. In some of the materials that have been used over again the ancient patterns may be discernible, as in the old pieces in a patchwork, or like Roman bricks or blocks of masonry that have been used a second time. Suess regarded Asia as like a building in which a Gothic roof has been built on Norman walls and perhaps over a Norman choir; according to Argand, Asia is like a building wholly of one period of architecture, the older materials used in its construction being stones that had been re-cut or lumps of masonry that had been incorporated in the walls or left in the foundations. According to Suess Asia is like a building which has been enlarged at long intervals, and in which each part reveals the culture and conditions of its time. Argand, on the contrary, considers that the effect of the Alpine Cycle on Asia was as complete a renovation as when a building is pulled down and a new edifice erected on the site. Argand, it is true, admits the existence in Asia of remnants of Upper Paleozoic mountains (which belong to Suess's Altaids); but he holds that the Asiatic Mountains of the Alpine Cycle were upraised on lines regardless of the Upper Paleozoic mountain movements. He declares that the whole of Asia was deformed by the "Tertiary paroxysm," and that the modern folds were independent of the ancient structures.[1] The essential difference appears to be that whereas Suess regarded the trend and range of the mountains of the Alpine Cycle as having been moulded by the fragments of the Altaids,

[1] Professor Berkey and Mr. F. K. Morris (*Geol. Mongolia* (1927), p. 413) have laid stress on the fact that the present aspect of the Altaid Mountains is due to faults of later date. The existing mountains are due to post-Altaid faults, just as the Variscan Mountains of Germany are horsts which owe their present form to Kainozoic faulting. Such fault block mountains may be classed as fragments of the Altaids, if they consist of masses folded during the late Paleozoic mountain formation.

Argand regards the Alpine movements as so overwhelming that their progress was not seriously interfered with by the Altaid blocks, which were lightly thrown aside.

Another important difference between Suess and Argand is regarding the effect of the ancient masses of crystalline rock. According to Suess, they have acted as passive resistant blocks which affected the trend of the mountains when the weaker material was crumpled into folds by the contraction of the earth's crust. According to Argand, on the other hand, these ancient masses were the active agents whose movements crumpled the intermediate areas into mountain chains, as ice-floes when they are driven ashore plough the beach materials into contorted drifts.

The present question regarding the structure of Asia is how much of Suess's scheme stands after the investigations and explorations of the past twenty-seven years. Personally I regard Suess's interpretation of Asia, apart from the eastern coastal area, which will be considered later, as fundamentally correct. It may be illustrated diagrammatically by the accompanying section. On the S. the peninsula of India is composed of pre-Paleozoic rocks and is covered only by land and freshwater deposits, except upon the margins. North of the subsidence trough of the Indo-Gangetic Plain rises the front of the Himalaya, overfolded and overthrust by movements from N. to S. The extent of the Himalayan overthrusts was not at first realized as in many places the rocks above and below the thrust-planes are of the same kinds; hence the evidence is not so obvious as where rocks quite different in structure and aspect have been brought together. North of the Himalaya extend high plateaux broken up by great faults; and the scarps have been weathered into the mountains of the Altaid type. On and beside those mountains there are sheets of Mesozoic or Kainozoic rocks, which in many places have been only gently tilted or may be horizontal. Thus Professor V. A. Obruchev remarks regarding the Altai that "the Paleozoic sediments are very strongly dislocated, but the younger lie almost horizontal."

5. Turkestan and the Reversal of the Asiatic Direction—What important changes on Suess's scheme have

been brought out by recent work and the present discussion? It is natural to turn first to the paper by Professor D. I. Mushketov on Eastern Turkestan, for that area abuts on Serindia, which is the main new factor introduced in Argand's hypothesis. Argand adopts the ancient term Serindia

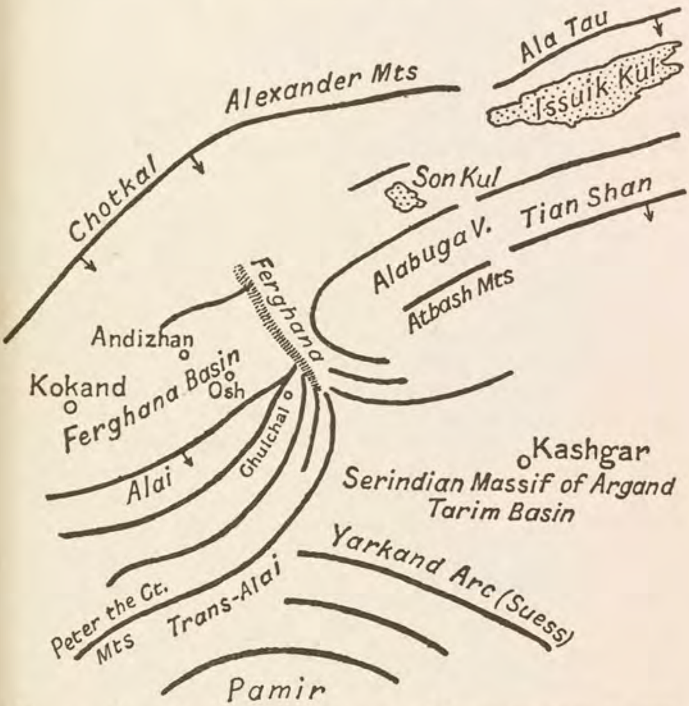


FIG. 3.—RELATIONS OF THE FERGHANA MOUNTAIN LINE TO THE TIAN SHAN AND ALAI MOUNTAINS.

for a hypothetical deep-seated mass, to which he attributes a dominating influence on the development of Central Asia. According to Argand Serindia is at present occupied by the Tarim Basin, between the Tian Shan on the N. and the Kuen Lun on the S. Both these ranges he represents as

overfolded towards that basin. He regards Serindia as geologically a huge almond-shaped mass of ancient rocks, which, by its resistance, buckled up both the Tian Shan and the Kuen Lun, and to the S.E. has cut across the divergent ends of the Altyn Tag. Professor D. I. Mushketov shows that the views of Eduard Suess, and those of his father, I. Mushketov, and of V. N. Veber, here require some modification. Those three authorities believed in the existence of two intersecting mountain chains of different ages ; the first is the Tian Shan, which trends roughly from W.S.W. to E.N.E., and was upheaved at the end of the Paleozoic ; the second is the Ferghana range, that trends at right angles to the Tian Shan, from N.N.W. to S.S.E., and is of Kainozoic age. D. I. Mushketov shows, however, that there are no such independent intersecting chains. He explains the Ferghana range as a great flexure which links up two members of the Tian Shan (the main Tian Shan to the E. and the Alai to the W.). The new evidence from this area proves there an important exception to the general statement that the Asiatic System is due to overfolds and overthrusts to the S. The Tian Shan is attributed to pressure from the N., and as its age is Upper Paleozoic it is one of the Altaids. But its structure near Ferghana was complicated in the Kainozoic Era by a northward movement from the Pamir, which produced overfolds to the N. and was followed by faulting. This northward advance is opposite to the ordinary Kainozoic or Himalayan movement in Asia. It is a local occurrence of the European direction in Central Asia.

This reversal of direction may be due to the influence of the great mountain area which runs N. and S. between Afghanistan and Baluchistan to the W. and India to the E., as the eastern end of the Mesopotamian-Persian Arc.

Its best-known unit is the Sulaiman Mountains, which trend N. and S., and consist of tilted Upper Mesozoic and Kainozoic rocks, with perhaps an Altaid core.[1] The country at the northern end of the Sulaimans has been involved in the cross E. to W. folds which have brought up, as in the Safed Koh,[2] some older rocks which appear to be part of an

[1] A. Fleming, *Quart. Journ. Geol. Soc.*, Vol. IX (1853), p. 348.
[2] C. L. Griesbach, "The Geology of the Saféd Koh," *Rec. Geol. Surv. India*, Vol. XXV (1892), pp. 69-70.

older Altaid mass. These old rocks also occur near Kabul. That this mountain mass which ranges S. of the Kabul River and W. of the Indus formed highland at the end of the Paleozoic and throughout the Lower Trias appears from the work of the late Sir Hubert Hayden.[1] His Khingil Series (Lower Trias) was deposited in a bay from the Tethys and, according to him, the Kabul districts and the area to the S. were part of the raised western margin of the Lower Trias sea of India and formed, throughout the Trias, the boundary between the Indian and European seas. This N.W. frontier land of India,

FIG. 4.—MOUNTAINS TO THE N.W. OF INDIA, WITH THE EUROPEAN DIRECTION OF FOLDING (SOUTH TO NORTH).

[1] H. Hayden, "The Geology of Northern Afghanistan," *Mem. Geol. Surv. India*, Vol. XXXIX (1911), pp. 76-80.

though involved in the Himalayan folding, has an older foundation which trended N. and S. and would have resisted the southward pressure from the Pamir. On both sides of this obstruction, owing to the weaker nature of the crust, the Himalayan lines curved southward, as the Persian-Mesopotamian Arc to the W. and the great arc of the Himalaya to the E. Between these two arcs the resistance of the Sulaiman Mountains and the Pamir Knot locally reversed the Asiatic movement.

Professor Mushketov's demonstration of these overthrusts from the S. is consistent with observations by the Geological Survey of India on the eastern side of the same mountain region; for Dr. D. N. Wadia [1] has discovered, on the borders of Hazara, Cretaceous and Eocene limestones that have been folded and overthrust to the N. and pushed over the Murree Beds (Oligocene). A post-Eocene northward thrust has also been shown by Professor von Klebelsberg [2] to the S. and S.E. of Ferghana, in the eastern Peter the Great Range, where a great thrust pushed the older rocks over contorted Eocene and Upper Cretaceous. Further W. overthrusts of the same age have the normal Asiatic southward direction; for in the Hissar range, to the S.E. of Samarkand and about 230 miles W.S.W. from Ferghana, isoclinal folds of the Eocene and Upper Cretaceous rocks dip to the S.S.E.; [3] and at Sanggardak, near Hissar, these beds have been overthrust by mica-schist which has been pushed from the N.-W.[4]

As the Tarim Basin contains marine Cretaceous rocks, it was clearly an old depression, and its buried pre-Paleozoic foundation is purely hypothetical. Professor Mushketov's account of Eastern Turkestan shows that Argand's hypothetical Serindian massif is unnecessary.

6. The Persian Arc—A flood of light has been thrown on the country to the S.-W. of Serindia by the important memoir on the Geology of Persia and the Persian Gulf contributed to this volume by Dr. H. de Böckh, Dr. G. M. Lees,

[1] *Cf.* E. H. Pascoe, General Report for 1926, *Rec. Geol. Surv. India*, Vol. IX (1927), p. 104.

[2] R. von Klebelsberg, *Beiträge zur Geologie West-Turkestans* (1922), especially Profile II, Sections Nos. 6-12.

[3] *Ibid.*, Profile V and p. 31. [4] *Ibid.*, Profile VI and p. 37.

and Mr. F. D. S. Richardson. The region between northern and north-eastern Persia and Arabia consists of a broad belt of folded and faulted mountains. These fold-mountains of north-eastern Persia are connected with the Hindu Kush System; in Central Persia, including the broad desert basin of the Dasht-i-Lut, the beds are practically unfolded. In the S. and S.W. of Persia are the highly-folded and faulted mountains which form the arc of Mesopotamia and of south Persia; they rise above the next unit, the plain of Mesopotamia and the basin of the Persian Gulf; still further S.W., beyond this valley, stands the ancient plateau of Arabia, which has acted as a foreland and is composed of old rocks. This belted arrangement of the Persian mountains is explained by Argand as due to the compression of the country by the southward advance of his Serindia and the drift to the N.E. of the great mass of Africa and Arabia. The whole Persian mountain region, according to Argand, is a strip of the earth's crust that has been buckled, fractured, and crushed into a smaller space between these two approaching masses. The structure of the Mesopotamian and Persian region, as discovered by the geological staff of the Anglo-Persian Oil Co., and explained by them in Chapter III, is inconsistent with this scheme. According to Argand's view the whole belt between Arabia and North Persia should have been folded; but its two strongly folded bands are separated by a scarcely folded basin. Instead of the rocks of the central basin having shared in the compression of the fold-mountains to the N.E. and S.W., the beds on the floor of the central basin of Persia have undergone only gentle folding, and none of Alpine intensity. Instead of this area—part of the Median Mass of de Böckh—having been a passive block that was compressed between Africa and Serindia, it was more likely an active agent in the compression of the fold bands beside it. Its nature as an ancient stable mass is proved, whereas that of Serindia is purely hypothetical, and is rejected by Professor Mushketov.

The best test for Argand's explanation of the structure of south-western Asia is as to the agreement of the dates of his assumed movements with the facts discovered by Dr. de Böckh and his colleagues. According to Argand, Africa

was advancing northward against Europe and north-eastward against south-western Asia throughout the Mesozoic and during the Kainozoic up to the Miocene. Then in the late Pliocene the movement stopped, a reaction set in, and as the pressure was relaxed the Mediterranean was formed as a great irregular rift, leaving part of Africa stranded in Southern Europe, even as far N. as Central Switzerland. During the time when, according to this scheme, Persia should have been under intense compression from the advance of Africa and Arabia, the south-western part of the country was traversed by a broad open valley which was gradually sinking and being filled with evenly-spread sediments. The band which Dr. de Böckh and his colleagues have described as the Iran Geosynclinal contains Cretaceous deposits ranging from the Valangian to the Maastrichtian, and also some Lower Kainozoic. This geosynclinal development from the Lower Cretaceous to the Oligocene is quite inconsistent with the supposed compression of south-western Asia during that time by the north-eastward drift of Africa and Arabia.

Then again, the folding of south-western Persia occurred later than the date required by Argand's theory, which assigned it to a time when the country was actually under tension instead of under the required compression. The intense folding of south-western Persia is shown, in confirmation of the early work of Loftus, to have been due to strong pressure in and after the late Pliocene, for beds containing the bones of the three-toed horse, the *Hipparion*, have been violently compressed and overthrust.

These disturbances occurred when, according to Argand, Africa was receding from Asia in the Pliocene reaction. Before the time of that folding the Red Sea and the Great Rift Valley were already in existence, for they date back to at least the Oligocene. As they were formed by tension the mass of Africa could have exerted no violent pressure on south-western Asia later than that period; and the compression of Persia would have been due only to pressure from Arabia without any support from Africa.

Further, it is part of the arguments both of Wegener and Argand that in late Kainozoic times India and Africa were drifting apart, and so producing the Arabian Sea; but at

that very time south-western Persia was undergoing compression of Alpine intensity.

Another serious disagreement between Argand's hypothesis and the facts concerns the whole of western Asia. The view that Eur-Africa (*i.e.* Europe and Africa, inclusive or exclusive of Arabia) was separated from eastern Asia and India by the submergence of a belt from the Arabian Sea to the Kara Sea has been often expressed, as, *e.g.* in the map by Ortmann.[1] In harmony with this view, Argand [2] claims that a low belt across western Asia connected the Indian and Arctic Oceans by a channel from the Gulf of Oman to the Kara Sea. The work of Dr. Lees and Mr. Washington Gray has, however, shown that Oman was part of an old chain which runs N. and S. almost at right angles to the course of the main folds of southern Persia, and has had a strikingly different geological history from them. In the main folded belt of Persia there is little evidence of mountain-forming movements after the Paleozoic until late in the Kainozoic; in Oman, on the contrary, as in the eastern Alps, the country was contorted by Cretaceous mountain-forming movements which were pre-Cenomanian. They correspond to the pre-Gosau movements in the eastern Alps. Oman was certainly not continued by a depression across southern Persia, but as a mountain ridge that extended into Central Persia. That basin has been occupied by the sea for short intervals at different periods, including, according to Dr. de Böckh, Dr. G. M. Lees, and F. D. S. Richardson, the Cambrian, Middle and Upper Devonian, Carboniferous, Permian, Trias, Jurassic, from the Aptian to the Upper Cretaceous, Middle Eocene and Aquitanian (Upper Oligocene). Central Persia has, nevertheless, been generally a raised area, and in Upper Kainozoic times gives no evidence of the submergence by which, according to the Argand hypothesis, most of Asia was separated from western Eurasia by the connection of the Kara and Arabian seas.

[1] A. Ortmann, "Tert. Archhelenis," *Amer. Nat.*, Vol. XLIV (1910), pp. 237-42; *cf.* Scharff, *Distribution of Life in America* (1911), opp. p. 382.

[2] E. Argand, "La Tectonique de l'Asie," *Congrès Géol. Internat.*, Sess. XIII, Vol. I, p. 191.

7. THE HIMALAYA—For the Himalayan Arc itself the recent work of the Geological Survey of India shows that the interpretation of the Himalaya based on the earlier surveys of Lydekker (1876), Medlicott (1864), and R. D. Oldham (1888)[1] must be greatly changed. The new conclusions have been briefly summarized by Sir Edwin Pascoe,[2] and are stated in Mr. W. D. West's contribution to this volume (Chap. V.). Near Simla the Blaini "group," which includes a famous glacial boulder clay, was formerly assigned by Griesbach to the Silurian, and has been referred back to the pre-Paleozoic; but, according to the newer evidence, it is probably Upper Carboniferous. Upon the Blaini rest some metamorphic rocks; the upper division was called the Krol and was assigned to the Upper Trias; a lower division, the Infra-Krol, was referred to either Lower Trias or Permian. The metamorphic rocks were thus regarded as schists and gneiss of Mesozoic, or perhaps partly Upper Paleozoic age. The evidence, however, obtained by Dr. H. G. E. Pilgrim and Mr. W. D. West shows that they are old rocks overthrust on to the Blaini beds.[3] Sir Thomas Holland [4] and Sir H. Hayden [5] had previously concluded that the unfossiliferous sediments assigned to the Krol, Infra-Krol, Jaunsar and Baxa rocks, instead of belonging to various Paleozoic and Mesozoic Systems, are all pre-Paleozoic, and correspond in age to the Purana System of the Indian peninsula.

These supposed Mesozoic and Upper Paleozoic Himalayan schists and gneiss therefore follow many others into the pre-Cambrian. The occurrence of metamorphic rocks lying on

[1] H. B. Medlicott, "Southern Himalaya between Ganges and Ravee," *Mem. Geol. Surv. India,* Vol. III, Part II (1864); R. Lydekker, "Geol. Kashmir," *ibid.*, Vol. XXII (1883); R. D. Oldham, "Sequence Pre-Tertiary Simla Region," *Rec. Geol. Surv. India,* Vol. XXI (1888), pp. 130-43.

[2] *Cf.* E. H. Pascoe, General Report for 1925, *Rec. Geol. Surv. India,* Vol. LIX (1926), pp. 106-8.

[3] "The Structure and Correlation of the Simla Rocks," *Mem. Geol. Surv. India,* Vol. LIII (1928).

[4] T. H. Holland, General Report, *Rec. Geol. Surv. India,* Vol. XXXII (1905), p. 156.

[5] H. Hayden in Burrard and Hayden, *Geography and Geology of the Himalaya Mountains and Tibet* (1908), p. 227.

non-metamorphic has been observed elsewhere in the north-western Himalaya, and is probably also due to overthrusting, which will probably prove to be more extensive in the Himalaya than has been hitherto recognized ; for such movements are less conspicuous where both the thrust and the overthrust rocks are similar than where schists have been pushed on to comparatively unaltered sediments.

The evidence for the existence of Paleozoic metamorphic rocks in the Himalaya has therefore collapsed ; but the general interpretation of the Himalaya as a mountain chain of the Alpine type, being due to pressure from the N. and to movements which lasted into and even later than the Pliocene, is apparently unassailable.

8. Mongolia and the Gobi—The nature of the country on the eastern border of Central Asia in Mongolia and the Gobi district has been worked out during the American Museum Mongolian Expedition by Professor C. P. Berkey and Mr. F. K. Morris, and described in their *Geology of Mongolia* (1927).[1] They divide the tectonic mountains of the Gobi district into five classes ; three of them, including the Altai, are fault blocks ; one consists of gently uplifted peneplaned masses which have been deeply dissected ; the fifth consists of intensely folded old rocks, and are now low maturely dissected hills. These folded and faulted mountains, according to Berkey and Morris, occupy most of Asia. Many of their sections show intense folding in their basement beds, while the over-lying Mesozoic and later rocks are faulted and either not folded or only gently folded, as for example in their Fig. 56, p. 134, of the section from the Arishan hot springs south-westward toward the Altai Mountains. The Altai side of that section is a great granite batholith, and an intensely folded series of slates and graywackes ; these rocks have been injected by granite tongues, and have undergone some contact metamorphism ; but it should be noted, in reference to the view that the granitic intrusions may be responsible for the regional metamorphism, that the alteration beside these granites is confined to a narrow band on the contact. The old folded series is there faulted against

[1] Berkey and Morris, *Geology of Mongolia*, Vol. I, pp. 34-6.

Jurassic rocks which have only a gentle dip. In some places the Mesozoic rocks are practically horizontal. This relation is shown by Berkey and Morris to hold both for the Tian Shan and the eastern Altai. The Tian Shan rise in the Bogdo-Ola to heights of over 21,000 ft., and have cliffs of 10,000 ft. sheer. The mountains consist of unfossiliferous slates, quartzites, altered eruptive rocks, etc., which have been attributed to the Carboniferous or Permian; but Berkey and Morris are obviously inclined to regard them as much older owing to the complete absence of fossils. The old rocks are folded and metamorphosed; their intense folding was completed before the deposition of the Jurassic rocks and the faulting which formed the existing mountains. The Talu-Ola, the Nan Shan, the Ala Shan, the In Shan, and the front of the Tian Shan are attributed to faulting; and Berkey and Morris point out, in agreement with Obruchev (1915, p. 321), that the faulting was much later than the folding. They differ from Suess mainly by assigning a long interval of time between these two processes.

Professor Berkey has stated some of the general results in Chapter VII of this volume. Special reference may be made to his conclusion that the metamorphic rocks of the Gobi are all pre-Cambrian, and that at no later time were the rocks altered into schists. Even the great Mongolian granite, says Professor Berkey, "accomplished little in modification of the rocks themselves." The post-Altaid movements in the Gobi were vertical with local folding, but "no marked folding." Though Professor Berkey and Mr. Morris lay stress on the independence of the folding and faulting in these mountain ranges, they recognize that the mountains were formed by intense folding near the end of the Paleozoic. Such mountains, in view of their date of formation, may be included in Suess's group of Altaids. The most significant of the conclusions of Berkey and Morris is that the successive post-Cambrian revolutions, that made both the fold and fault mountains, worked throughout on much the same lines and in the same direction. This uniformity since the pre-Cambrian indicates that the agent that made the mountains was some slow persistent cause, such as the contraction of the earth's crust.

9. Siberia and the Arc of Verkhoyansk—Passing to Siberia, Professor W. A. Obruchev, in his valuable monograph, *Geologie von Siberien* (1926), agrees with Suess on the essential problems. He develops Suess's classification on lines opposite from the direction of Argand; thus he accepts the Primitive Nucleus of Asia and places on it a series of Caledonid chains. Obruchev also subdivides the Altaids and separates from them the Hercynids of the Devonian and Carboniferous Periods; the Altaids he assigns to the post-Carboniferous. He also records in Asia various occurrences of Upper Mesozoic mountains (Kimmeridgids and Saxonids), of which one line occurs E. of the Urals; others constitute the Sikhota Alin Mountains and the Arc of Verkhoyansk, and there are others on the south-western shore of the Sea of Okhotsk, and in the valley of the Kolyma in eastern Siberia. The Alpine Mountains form the axis of Sakhalin; but in Siberia, according to Obruchev, they are far less extensive than those assigned to the Alpine Cycle by Argand.

Obruchev therefore extends the age-succession of the Asiatic Mountains, and accepts not only Suess's three dates of main mountain development—those of the Primitive Nucleus, of the Altaids, and of the Alps and Eastern Arcs—but he adopts three additional epochs of mountain formation.

Argand has placed in N.E. Siberia a Kainozoic Alpine range, and that view is supported by the recent claim of Sergei Obruchev of the discovery of a Kainozoic fold-mountain range in the valley of the Indigirka River. Argand himself gives no adequate evidence of his East Siberian Alps, which are apparently based on the Verkhoyanski Arc. Professor W. A. Obruchev [1] quotes from Wollosowitsch the occurrence of folded Paleozoic and of Cretaceous beds in the Chara-ullach range (*i.e.* the north-western end of that arc E. of the Lower Lena) and also at the head of the Khroma River, 160 miles further E.

S. Obruchev's [2] new Cherski range, which is concentric within the Verkhoyanski Arc, is described as composed of

[1] W. A. Obruchev, *Geol. Siberien* (1926), pp. 341-2.

[2] S. Obruchev, "Discovery of a Great Range in North-East Siberia," *Geogr. Journ.*, Vol. LXX (1927), pp. 464-70.

folded Trias and intruded by post-Lower Cretaceous granite and diabase. No definite evidence is stated for the age of the Trias or the date of the folding. The Lower Cretaceous rocks are said to occur as patches, which suggests their deposition after the folding; if so, as in the Gobi district, the last folding would be pre-Cretaceous with later faulting, for the Cherski range is described by S. Obruchev as a horst. He

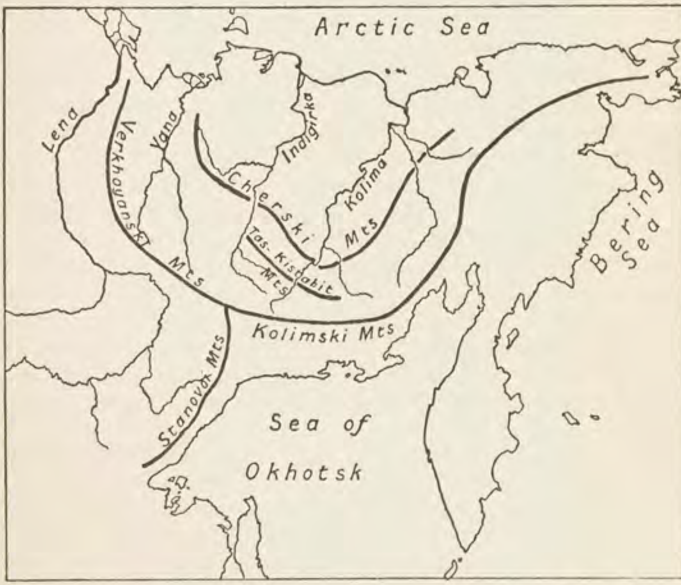


FIG. 5.—THE ARC OF VERKHOYANSK AND THE CHERSKI RANGE OF S. OBRUCHEV.

gives no information as to the direction of folding, which von Toll[1] reported in the Verkhoyanski Arc to be towards its interior, and therefore as from S. to N. and S.W. to N.E.

The full evidence for the Cherski range has not yet been published, and the existence of an Alpine range due to folding from N. to S. would not be expected there from the in-

[1] *Cf.* Suess, *Face of the Earth*, Vol. IV, pp. 342, 509.

formation available regarding the area to the S.; for the American-Mongolian Expedition and the recent work of the Geological Survey of China indicate the existence in northern China of great Kainozoic fault movements, but of no intense folds.

10. THE EASTERN MARGINAL ARCS—Suess's synthesis of Asia appears therefore still to hold the field as regards the Primitive Nucleus and the existence of a mountain system, the Altaid, that was earlier than and independent of the Alpine-Himalayan System, the course of which was modified by the Altaid remnants. As regards the relations of the mountains and island festoons along the eastern coast of Asia, Suess's scheme requires more serious amendment. His view of the structure of this part of Asia was probably inspired by his belief in the unity and comparatively modern age of the Pacific. He represented the eastern coast of Asia as bounded by a series of Eastern Marginal Arcs. Those arcs unquestionably exist, but are not fold-mountain chains.[1] The modern evidence is opposed to Suess's views of their origin and structure, and of their classification.[1] He included the Himalaya, which he correlated with the Dinaric Mountains of Europe and with the Arc of Yarkand, in the same series as the Eastern Marginal Arcs. He continued the Himalayan line eastward by a horseshoe bend around Assam, through the mountains of Western Burma, the Andaman Islands, the islands off Western Sumatra, and the Eastern Archipelago, till by another horseshoe bend through the Kei Islands the line curves back around the Banda Sea. Suess [2] had himself remarked that the northern arm of the supposed Banda Arc in the islands of Buru and Ceram is continued by the southern peninsula of New Guinea (Berau), and that the Timor arm is a parallel independent line; but in his sketch map [3] he followed Wichmann in connecting the

[1] Suess's view of the formation of the Eastern Marginal Arcs of Asia as arcuate folds due to southerly or south-easterly pressure from the interior of Asia is, however, expressed in the map by F. B. Taylor, in the recent symposium on *Theory of Continental Drift*, edited by Dr. W. A. J. M. van Waterschoot van der Gracht (1928), p. 165.

[2] Suess, *Face of the Earth*, III, p. 243.

[3] *Ibid.*, p. 235.

Timor and Ceram lines by a semi-circular line through the Kei Islands. He extended the line through Buru, Celebes, Borneo, the Philippines, Formosa, the Japanese Arc and the

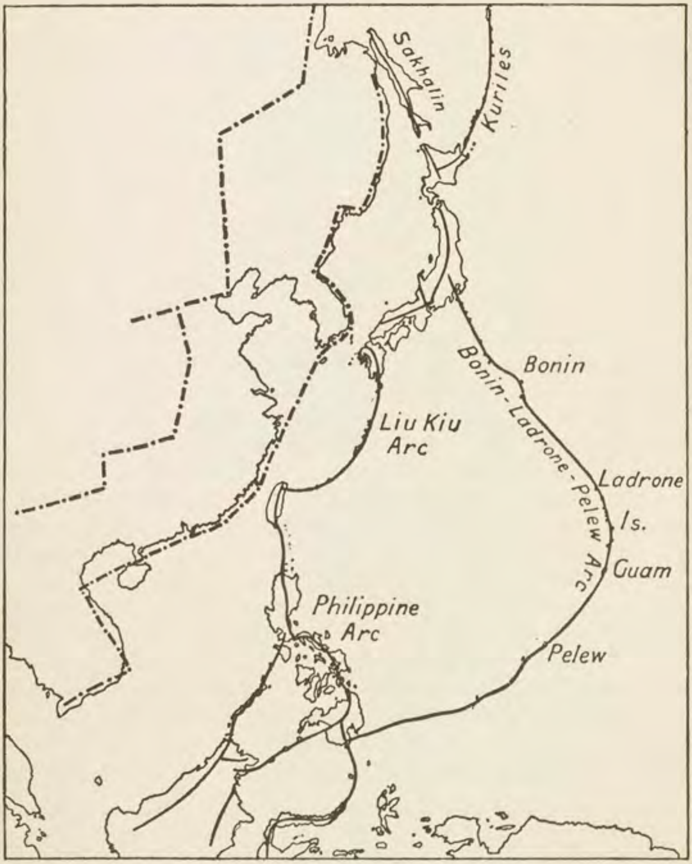


FIG. 6.—EASTERN ASIA WITH THE EASTERN MARGINAL ARCS OF SUESS AND THE FRACTURE LINES OF VON RICHTHOFEN.

— · — · The Fracture Lines of von Richthofen.
——— The Eastern Marginal Arcs of Suess.

Kurile Islands to Kamchatka. Suess, however, in the map expressing his final *Analysis of the Earth Surface* (Vol. V, Pl. I), ends the arc along the southern side of the Eastern Archipelago to the E. of the Banda Sea and does not give it the horseshoe bend back to Ceram ; and that island he represents as an extension of the main mountain axis of New Guinea. The parallel line to the N., through the Sula Islands. Misol,

FIG. 7.—THE MOUNTAIN LINES OF THE EASTERN EAST INDIES.

The islands and mountain lines in the East Indies from Celebes to New Guinea, north of Torres Strait and Northern Australia.
——— The Recurved Banda Arcs of Wichmann, Brouwer.
The continuation of the Malay Lines into New Guinea, according to Bohm, Suess, and Gregory (after Gregory, 1923).
· — · — · The Batanta, Berau, Humboldt Bay Line.
— ·· — ·· — Buru, Ceram, and mountain axis of New Guinea.
— ··· — ··· — The Sunda Line continued as southern mountains of New Guinea.

and the Berau Peninsula (the most north-westerly part) of New Guinea, is placed in a different category.

Suess [1] in 1888 defined these "arcs of Eastern Asia . . . as the recurved extremities of the great chains of Central Asia," and that view he retained although later on he recognized serious difficulties. He explained the marginal arcs

[1] E. Suess, *Face of the Earth*, II (1888), p. 204.

from Kamchatka to Formosa, and the island festoons, even as far into the Pacific as the Bonin and Ladrone Islands, as due to folds caused by outward pressure from the Primitive Nucleus. Suess's Eastern Marginal Arcs appear, however, to consist of many diverse elements. The horseshoe bend around the Banda Sea has been supported by Professor H. A. Brouwer,[1] but as I have previously pointed out,[2] the most significant strike of the rocks in the islands at the most easterly part of this Banda Arc is E. and W., indicating that the adjacent mountain lines continue eastward into New Guinea. The apparent arc may be explained as not a bent line of folding, but as the jagged rim of the area which, by foundering, formed the basin of the Banda Sea.

Similarly Japan is not a chain of Alpine fold-mountains, with the rocks striking along the course of the archipelago, but the stratified rocks have been disturbed by faults and the fault-blocks are still moving. The view that southern Japan is traversed by a predominantly E. to W. Altaid chain seems to me more correct than the reference of the non-volcanic mountains of Japan to the Alpine Cycle. Dr. E. Naumann's conclusion that the mountains that traverse Western Honshiu, the largest of the Japanese islands, and the adjacent islands of Kiu-Shiu and Shikoto are the detached fragments of the Chinese Altaids has received general support. These mountains have been called " the Paleozoic Mountains " of Japan.[3] Von Richthofen considered them an extension of the Tsinlin

[1] H. A. Brouwer. His latest statement is in his *Geology of the Netherlands East Indies* (1925), p. 53 ; but the account there of the strikes in the Kei Islands is less definite than that of Verbeek in his *Molukken Verslag* (1908). The difference of interpretation E. of the Banda Sea does not affect the rest of Brouwer's work on the geology of these mountain lines.

[2] J. W. Gregory, " The Banda Arc : Its Structure and Geographical Relations," *Geogr. Journ.*, Vol. LXII (1923), pp. 20-30 ; " The Geology of the Aru Islands," *Geol. Mag.* (1924), pp. 52-6.

[3] The facts in favour of this view are confirmed by Professor N. Yamasaki of Tokyo University in his recent *Geographical Sketch of Japan* (1928), p. 17. Also B. Koto, *Journ. Fac. Sci.*, Imp. Univ., Tokyo, Sec. II, Vol. II (1928), p. 266. The general acceptance of Suess's Eastern Arcs may be illustrated by the same author's remark (*ibid.*, p. 2), that the Japanese arcs are parts of the great Tertiary Circum-Pacific fold.

Shan of Central China. Haruki Yamawaki[1] expressed the view of many Japanese geographers in describing the Chugoku

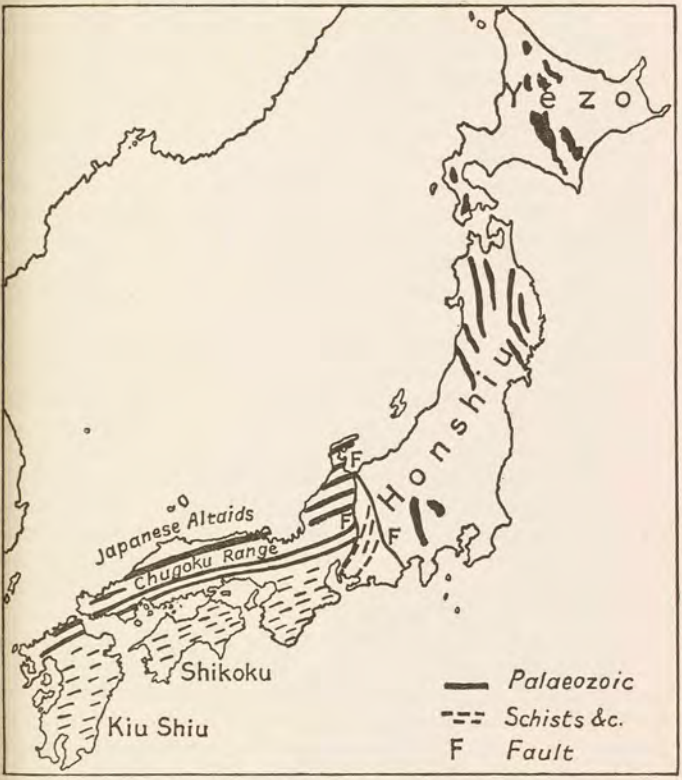


Fig. 8.—Relations of the Japanese Altaids to the Ranges in Eastern Japan.

range as a continuation of the Kuen Lun (Kung-lung) System of China.

Von Richthofen had begun his interpretation of eastern Asia and the eastern Arcs at the date of Suess's volume on

[1] *Japan in the Beginning of the Twentieth Century* (1903), pp. 17-18.

Asia, in the first of three important memoirs (1900-2) entitled *Geomorphologische Studien aus Ostasien*.[1] According to von Richthofen the dominant feature in these arcs is the faulting, and he describes the mountains of eastern Asia as a series of steps with fault scarp fronts. The mountainous zones consist of broad dissected plateaux, each a " Landstaffel," or the tread of a step, with on its seaward side a " Staffelrand " or steep slope, which in most cases is a dissected fault scarp or some other tectonic hillside.

These " Staffelrand " are curved and in nearly every case the convex side is towards the Pacific ; the beds beside them are tilted and may be locally folded ; but they are primarily the sides of fault-blocks, and the folds in them are either due to earlier mountain cycles, or are secondary to the faulting.

The most important and longest of these marginal mountains is the Great Khingan range. Suess [2] declared that it " is certainly a folded range," although von Richthofen had previously represented it as a fracture line. Though some of the Great Khingan rocks may be folded, von Richthofen's view of its structure seems correct, and is quite consistent with my observations when crossing it on the Siberian Railway in 1914. Greater opportunities than usual were then afforded for examining the country beside the railway during the halts when the train in front of us " was exercising its horses."

Whether the Khingan line is due to faulting or to a single fold (a monocline) is a matter of detail. Bailey Willis [3] favours a flexure, but in at least one traverse von Richthofen saw definite evidence of step-faulting. The essential point regarding the Great Khingan is whether the range was thrown up by the folding of a strip of the earth's crust by compres-

[1] Von Richthofen, *Sitz. k. Akad. Wiss.*, Berlin (1900), pp. 888-925 ; (1901), pp. 782-808 ; (1902), pp. 944-75. A useful summary with translations of some passages has been issued by Professor W. H. Hobbs, " Tectonic Geography of Eastern Asia," *Amer. Geol.*, Vol. XXXIV (1904), pp. 69-80, 141-51, 214-26, 283-91, 371-8.

[2] Suess, *Face of the Earth*, Vol. III (1901), p. 263 ; for description of its structure see *ibid.*, pp. 116-21.

[3] Bailey Willis, "Research in China," *Carnegie Instit.*, Vol. II (1907), p. 106.

sion, or has been left as high land owing to the sinking of the country to the south-east. Whether the rocks yielded by bending or snapping is immaterial. The evidence seems overwhelming that von Richthofen was right, and that the Khingan range was left upraised by the subsidence of the area on the Pacific side, and was not upheaved by lateral compression. Hence von Richthofen's view of the structure of the eastern margin of Asia seems truer than the interpretation of Suess. He,[1] it is true, recognized facts which he obviously found difficult to reconcile with his theory; he remarked, for example, that the fractures in the Sikhota Alin, the coastal mountain chain on the mainland W. of Japan, do not coincide with the folds in the chain.

The Eastern Marginal Arcs, of course, include some fold-mountain chains, as in Japan; but the folded parts are fragments of Upper Paleozoic mountains and are relics of the Altaids, or are later secondary folds. The main arcs are due to fracturing of the eastern edge of Asia concurrently with the formation of the Pacific Ocean by the subsidence of its floor.

Suess's view of the eastern border of Asia seems to me the greatest defect in his synthesis of Asia. Argand adopts and extends Suess's views on this branch of the subject. Argand adopts the Eastern Marginal Arcs as the eastern extension of the principal Alpine chains of Eurasia, and carries one continuous fold-mountain line around the Banda Sea and through Burma, the Philippines, and the East Asiatic Island festoons to Kamchatka; but there he bends it back again westward through north-eastern Siberia, by assigning the Verkhoyanski Arc to the Alpine Cycle.

11. South-Eastern Asia—Argand's interpretation of south-eastern Asia inadequately recognizes the geological work that had been done in that area since the time of Suess, whose arrangement of the Burma and Malay Arcs appeared the most plausible explanation of the facts known in 1900. Later work, however, indicates that the main continuation of the Himalaya is eastward across southern China, and that the Burmese-Malayan Arc was an off-lying loop like that of

[1] Suess, *Face of the Earth*, Vol. III (1901), p. 147.

the Apennines and the Atlas around the western Mediterranean. Indications of a chain of fold-mountains of an Alpine type across southern China are given in the descriptions by von Richthofen, and have been confirmed by the Geological Survey of Indo-China and Tongking.[1] The work for that Survey by Deprat has been severely condemned in France, and some of his results have been disproved. Cautious students of Deprat's maps and sections would treat many of them as diagrammatic sketches; but the revision of his work by Professor Jacob [2] has confirmed the more striking conclusions that have been based on Deprat's surveys, though in some cases a simpler interpretation of the facts is possible. The work of the Geological Survey of Indo-China has made it clear that in south-eastern Yunnan and Tongking a broad belt of country was intensely compressed in the Middle Kainozoic by pressure from the N.[3] This compression was followed by the normal reaction, and violent earth-movements in the Upper Kainozoic produced great faults and rift valleys.

The observations of my son and myself in western Yunnan in 1922, though we found less sensational overthrusts than those described by Deprat, show that an older mountain structure due to folding of the Altaid Cycle has been crossed there by folding due to pressure from the north during the Alpine Cycle.[4] The existence across southern China of a broad belt of mountainous country, which was due to intense compression with overfolding and overthrusting from the N. during the Middle Kainozoic, is indicated by the evidence of the mercury mines of Kei-chow and by von Richthofen's

[1] J. Deprat, "Étude Géologique du Yun-nan Oriental," *Mém. Serv. Géol. Indochine*, Vol. I, Part I; *Géologie Générale* (1912); and "Études Géologiques Région septentrionale du Haut-Tonkin," *ibid.*, Vol. IV, Part IV (1915).

[2] C. Jacob and R. Bourett, "Itinéraire Géologique dans le Nord du Tonkin," *Bull. Serv. Geol. Indochine*, Vol. IX, fasc. 1 (1920).

[3] In Hong Kong the folding is interpreted as Miocene by Grabau, "A Lower Cretaceous Ammonite from Hong Kong, S. China," *Bull. Geol. Surv. China*, No. 5, Part II (1923), p. 207.

[4] J. W. and C. J. Gregory, "Geology and Physical Geography of Chinese Tibet, and its Relations to the Mountain System of South-Eastern Asia," *Phil. Trans.*, Ser. B., Vol. 213 (1925), pp. 234-40.

observations further E. This view is now adopted by Mr. Wong[1] on behalf of the Geological Survey of China.

In Northern China there is evidence of great Oligocene earth-movements; but in the N.W., in the provinces of Shansi and Shensi, Dr. J. Gunnar Anderson[2] described faults of that date with throws of 10,000 ft. and 14,000 ft., which have made rift valleys and still existing fault scarps. In some parts of northern China he[3] records Oligocene folds, as in Shantung, Kansu, and Fengtien (near Mukden), but the folding was gentle and local. L. F. Yih[4] has shown that W. of Pekin, all the beds from the pre-Cambrian to the Jurassic have been evenly folded—showing the absence of Altaids there—and the later movements were faults. T'an[5] has proved for Shantung that the folding was subordinate and local, and followed by Oligocene faults which are described as huge. Yih and Hsieh[6] have described the close folding in the eastern Yangtze Valley and determined its age as post-Cretaceous, and probably intermediate between the Eocene and Oligocene; Hsieh and Liu[7] assign the mountain-forming movements in S.W. Hupeh to the post-Cretaceous, and consider that there was no folding in that area between the pre-Paleozoic and the early Kainozoic. The existence of a belt of Kainozoic folding and thrusting is inconsistent with Argand's representation of south-eastern Asia. He accepts large areas in Central Asia as composed of "Hercynian

[1] W. H. Wong, "Crustal Movements and Igneous Activities in Eastern China since Mesozoic Time," *Bull. Geol. Soc. China*, Vol. VI, No. 1 (1927), p. 31.

[2] J. Gunnar Anderson, "Essays on the Cenozoic of Northern China," *Mem. Geol. Surv. China*, Ser. A, No. 3 (1923), pp. 145, 147.

[3] *Ibid.*, pp. 150, 151.

[4] L. F. Yih, "The Geology of Hsi Shan or the Western Hills of Peking," *Mem. Geol. Surv. China*, Ser. A, No. 1 (1920), p. 58.

[5] H. C. T'an, "New Research in the Mesozoic and early Tertiary Geology in Shantung," *Bull. Geol. Surv. China*, No. 5, Part II (1923), p. 130.

[6] L. F. Yih and C. Y. Hsieh, "Geologic Structure and Physiographic History of the Yangtze Valley below Wu Shan," *Bull. Geol. Surv. China*, No. 7 (1925), pp. 93, 94, 102-5, 108. Their work also indicates that the folding in the Yangtze Valley, attributed by Bailey Willis to the Jurassic, is post-Cretaceous.

[7] C. Y. Hsieh and C. C. Liu, "Geological and Mineral Resources of South-West Hupeh," *Bull. Geol. Surv. China*, No. 9 (1927), p. 47.

material," including both the Tian Shan and the Kuen Lun ; and he represents the Hercynian band as bifurcating at the eastern end of the Kuen Lun, one branch continuing across Central China and emerging on the coast on both sides of the mouth of the Yangtze-Kiang. The other branch passes southward along the eastern margin of Assam and continues as the Burmese Arc. According to this view, the mountains of western Yunnan and eastern Burma are Alpine ground-folds composed of "Hercynian material"; Burma and the adjacent area of China are traversed by a N. to S. mountain range, which consists of Alpine material to the W. and of Hercynian material to the E., and both the mountain chains were folded at the same date, the Middle Kainozoic. The facts, as far as I saw them in 1922, seem fundamentally different. Altaid mountains occur in Yunnan and eastern Burma, but consist of the same materials as the younger mountains to the W. of them. The Hercynian material of Argand passes westward into his Alpine chains. The difference between the two bands is in the date of the movements ; the eastern area was folded in the Upper Paleozoic on lines that here run N. and S. ; and the Alpine movements are a later independent series which cuts across the Hercynian or Altaid lines, and continues eastward into southern China instead of going southward along the Burmese Arc. One series (regarded as the main Himalayan line) passes eastward through the Ta-shueh Shan, and other mountains to the S. of that range, into southern China.[1] Thence they probably continued into the Pacific, and their eastern extensions have been snapped off by the great marginal faults of eastern Asia. Parallel lines further S. are probably continued through the Eastern Archipelago and through the two main mountain lines of New Guinea into the Pacific.

The independent adoption of conclusions similar to the above is expressed in Staub's map of the Alpine "Leitlinien,"[2]

[1] *Cf.* J. W. and C. J. Gregory (1925), *op. cit.*, pp. 255-6.

[2] R. Staub, *Der Bewegungsmechanismus der Erde* (1928). Staub follows Suess by maintenance of the three great Archean coigns which have formed the nuclei of North America and Eurasia ; and his map well illustrates the importance of Suess's Altaids, though Staub does not adopt that term.

which in important respects maintains Suess's fundamental conceptions and differs from them by natural developments. It is true that Staub's map still represents Japan, Sakhalin, and the East Asiatic Island festoons as parts of the Alpine System ; but he adopts the lines which my son and I have advocated for southern and eastern China, as he continues the Kuen Lun System eastward across China to the coast near Shanghai, while one of the intermediate chains between the Himalaya and the Kuen Lun, after a curve southward in Yunnan, bends northward and goes eastward across China. In compliance with Dutch authorities he twists the southern fold of the Eastern Archipelago through a double horseshoe bend, as if it were frightened of Ceram ; but the continuation of the southern fold line past the Kei Islands into the southern chain of New Guinea appears the more natural course. Staub's map is therefore an important step towards recognition of the continuation of the Himalayan Mountain lines across south-eastern Asia until they disappear into the Pacific.

12. Conclusions—The mountain structure of south-eastern Asia appears then to include two great mountain systems—the Altaid and the Alpine-Himalayan. Suess's plan has to be extended farther E. than he applied it, his nomenclature and classification have to be modified, and a different interpretation given of the East Asiatic coast.

There is, moreover, a steady drift of opinion towards the view which I expressed in 1919 and 1921,[1] namely that during the process of deformation of the earth the great mass of Africa acted as the hinterland or backland which, pressing northward against southern Europe, crumpled it against the northern forelands, and that in Asia the direction was reversed because the great mass which acted there as the driving hinterland lay to the N. and the great depression in the crust lay to the S. Accordingly the dominant Asiatic movement was from N. to S. We now know from the work of Mushketov, Klebelsberg, Wadia, and others, that the Asiatic direction was locally reversed opposite the mass of the Sulaiman

[1] Gregory, *The Rift Valleys and Geology of East Africa* (1921) ; map, p. 16 and opp. p. 358 ; pp. 373-5.

Mountains and the Pamir which acted as a hinterland between the two forelands of Arabia and the Indian Peninsula. Further, that the great meridional belt of ruptures that made the Great Rift Valley of the Jordan, the Red Sea, and East Africa was due to the stresses between the northward movements to the W. of it and the southward movements to the E. These views may be extended to south-eastern Asia in accordance with the evidence collected by the French geologists in Indo-China and that obtained by my son and myself in Chinese Tibet, for the N. to S. movements in that area are due to the pressure of the hinterland of northern China against the foreland of Farther India and Indo-China. That this movement continued farther eastward into the Pacific is shown by the fact that in China, Japan, and the Indies, Asiatic ranges that trend E. to W. pass out indefinitely into the Pacific. They were broken off by subsidences which enlarged the Pacific Ocean in the late Oligocene, contemporary with the extension of the North Atlantic to the W. of Europe.

CHAPTER II

THE EUROPEAN ALTAIDS AND THEIR CORRELATION TO THE ASIATIC STRUCTURE

By Professor F. E. Suess, LL.D., University of Vienna

The name Altaids was given by Suess to a system of mountain folds that comprises the main portion of Eurasia extending from the Vertex, or according to Gregory's expression, from the Nucleus of the Russian Altai through the central part of Asia to the mountainous plateau of Tibet. In the East Indies the extremities of this system comprise the Sunda Arc as far east as the Banda Sea. To the W. they include not only the remote branches of the Variscan and Armorican chains of Middle Europe, but also, across the Atlantic Ocean, the so-called American Altaids in the Appalachians, still traceable as far as the hills of Oklahoma, W. of the Mississippi. Even the Alpids, that is the Kainozoic mountain ranges of the Mediterranean, are regarded by Suess as a posthumous group of the Altaids, and their origin is attributed to the pressure of the older Altaid framework surrounding them. It should be borne in mind that when this classification was brought forward, stronger emphasis was laid on the importance in structural geology of trend-lines of strata than on the morphological outlines.

Grouping the different kinds of folds under one general term obviously implied their development by a common system of dynamical forces, arising from the Altai-Nucleus and spreading far to the S., E., and W. The limit between the Siberian tableland and the Central Asiatic region is a sharply-defined zone of fractures, divided into two projecting

sinuosities—the Baikal or Primitive Nucleus, and the so-called Altai-Nucleus. The independence of the Western or Altai Nucleus is evident from its folding having continued into the Carboniferous Period, whereas the Primitive Nucleus is pre-Paleozoic.

The movements radiating from the Altai Nucleus spread far beyond the scope of the Primitive Nucleus and affect the bulk of the continent. They are not only separated in space from the Primitive Nucleus and its peripheral formations, but also belong to a different period of folding. Nevertheless, the question of the age of folding is not an essential element in Suess's conception of the Altaids, which differs in this respect from the French conception of the Caledonian and the Hercynian folding. Suess's word, Altaid, is not an extended application of the terms Variscan and Armorican, for it comprises the recent arcs of the Sunda Islands and Japan, and the Tsin-ling Shan is also considered as a branch of the waves radiating from the Altai Nucleus.

The dynamical sense of the conception is fully expressed in the comparison with the waves of a sheet of water stirred at a point between Irtisch and Tarbagatai and propagated with many deflections to the extreme E. and S. of Asia and to the remote Atlantic coast of Europe.[1]

The first comprehensive classification of this system incorporated and summarized the scientific knowledge available at the time; but recent progress has provided more exact distinctions. The different significance of the various trend-lines had then been indicated, but had not been fully worked out. The difference was referred to the lack of individuality in the crowded systems of folds, so that in the Nan Shan and elsewhere chains of gneiss and of sedimentary rocks appear alternately and are intruded by irregular bosses of granite. Such crowded ranges are regarded as waves belonging to a common movement, in contrast with the isolated younger chains, like the Alps and the Himalaya. These crowded ranges have a distinctive structure owing to the absence of an alien foreland, and they may be compared with the regular waves of the open sea in contrast with the confused breakers on a shore.

[1] Suess, *Face of the Earth*, Vol. III, p. 197.

It had also been found that some of the Asiatic mountain chains had each been elevated as a massive block.

Two conceptions that are developed in the sequel lead to a closer understanding of the Asiatic structure. The first is the just appreciation of morphological features as an effect of recent tectonic movements. The second is a sharper discrimination between the significance of the strike of the rocks which form part of a pronounced zone of folding (the so-called orogens), and of those which, after having been irregularly folded and usually intruded by batholiths, have subsequently been moved as a whole without further deformation. Rocks belonging to these two categories are distinguished by contrasted types of metamorphism.

Professor J. W. Gregory has directed attention to the first of these points [1] in his review of Suess's *Classification of Eurasian Mountains*. We ought not to neglect the fact that every morphology is of relatively recent date and is the effect of special tectonic movements, which may or may not coincide with the strike of younger or older folds. Furthermore, this idea is expressed in the term "Folded Mountainblock" (Faltenblockgebirge), which mountain type, according to Obruchev (*Geol. Siberien*, 1926), dominates the whole of Central Asia.

Argand's admirable synthesis of Asiatic structures is chiefly based on the same idea. One of the leading factors in Argand's explanation is the distinction of the "plis de fond" or "foundation-folds," or "ground-folds," [2] and the "plis de couverture" or "cover-folds." The last-named are constructed out of "new material" that has not yet been used for mountain-making. It is the mass of pliable sediments of which the gently-folded recent cordilleras are formed. The ground-folds are geological phenomena of an incomparably larger style. They consist of the rigid older material that has been repeatedly worked up; and this material may besides be stiffened by crystallization and magmatic intrusion. As compared with cover-folds, ground-folds move much greater weights with much greater expenditure of

[1] *Geogr. Journ.*, Vol. XLV (1915), pp. 505-7.

[2] Mr. E. B. Bailey suggests "foundation-folds" instead of the usually adopted rendering, "ground-folds."

energy. This is shown by their greater breadth and greater radius of curvature. Older chains with an inner structure of the same type, as is shown by newly-folded material, are incorporated as inert masses in the ground-folds. Both systems, younger and older, may remain quite independent as regards their strike; they may run parallel or may cross each other.

The ground-folds may start as a low arch of any broad or elongated shape. But the further development will be governed by tangential stress, and will inevitably soon produce rupturing in rigid material. This rupturing will be followed by overthrusts which may here attain the largest proportions. But in the absence of pliable unfolded sediments, as true nappes of the Alpine type are not possible, the overthrusts are developed less conspicuously. In spite of perhaps far-reaching horizontal displacements they remain in this case as the so-called "Charriages à sec" or the "dry overthrusts" of Argand.

It would appear that the French interpretation of the term "plissement" comprises a greater variety of different kinds of dislocations than the English and German "folding" and "faltung." They call "plissement" any kind of deformation produced by tangential movement, so that the folded block-mountains of Obruchev, as well as warping, tilting, and faulting, belong to the phenomena of the "plissement de fond" of Argand.

Suess briefly threw out the idea that the whole southern border of Eurasia advances in a series of great folds towards Indo-Africa. He mentioned Griessbach's statement that, as one stands in front of the over-folded chains of the "Himalaya, there seems to have been a movement of the whole mass of Asia toward the S."

It was Taylor who, relying on Suess's interpretation of Asiatic structure, first explained the whole structure of Asia and that of other continents as the result of crust-creep from the poles, which acted with maximum deforming force in high latitudes, probably connected with the flattening of the lithosphere.

Argand's exposition of the continent has presented these crust-creep movements in a comprehensible form. The pro-

cess is analysed in detail. He distinguishes a series of epochs of folding, or "cycles," as he calls them. The Caledonian Cycle is not clearly defined in Asia. The Hercynian Cycle is very conspicuous in the interior of the continent. The realm of the Tethys with Tibet, the Himalaya, the ranges of Iran, the Burmese and Malay Arcs, the eastern Asiatic island ranges, etc., all belong to the Alpine Cycle. Further investigations will probably show that these cycles are not strictly separable from each other, and that it is with the growing thickness of the sediments in the region of the Tethys that the younger folding becomes more prominent. The deeper-lying fold-systems, which Argand differentiates under the cycle of Paleozoic conformities, are not exhibited in the arrangement of the existing mountain formations of Central Asia. The folded blocks themselves, on the other hand, are an essential part in this arrangement.

The "Leitmotiv" of the Asiatic structure remains, according to Argand, the southward creep or flow of the whole continent. What is new in his conception is the separation of the recent movements from the anterior structure. He shows that the old structures, recognizable in the strike and trend of the schists, are not essential in the features that express the main movements of the continent, but are the Alpine ground-folds which have seized material of older or later date in Mesozoic or Kainozoic times. The whole continent becomes a unity of Alpine movement. It almost flows before our eyes. This conception is in harmony with the observations of the Russian and American geologists concerning the recent block-movements across the interior from the Primitive Nucleus to the Tibetan plateau.

The irregularities, the deviations and the distortions of the folds are produced by the lack of homogeneity in the continental block and by the intercalations of more rigid and less pliable portions.

Argand's conclusions are convincing[1] concerning the effect of the rigid Serindian platform (Eastern Turkestan) on the surrounding chains of the Tian Shan to the N. and of the Kuen Lun to the S.

[1] But *cf.* Prof. Mushketov's conclusions, p. 178; also pp. 14-15.

The resistance of the great Indian Peninsula not only caused an enormous deviation of the southward pressing continent, but also its partition into three main segments.

Suess and Argand agree in considering Europe as an appendix of Asia, and in the opinion that it has passed through the same history as Asia proper, so that in it there reappear the essential features of the Asiatic structure. But the reasoning of both authors is not identical.

According to Suess the Variscan and Armorican folds of middle and western Europe belong to the Altaids, owing to the common age of their folding, the common character of their structural features, and also owing to indications of their connection by tectonic lines that approach from the Caspian Sea through the Donetz Basin of southern Russia. Moreover, on account of a similarity of the structures and of marine transgressions, Suess included in the same class of chains the Cor-Sardinian block (Corsica and Sardinia), and even the mountains of the African Atlas to the S.

Argand, for his part, recognizes in the distribution of the horsts and basins of Europe the extremities of the Asiatic ground-folds with axes of elevation and subsidence. According to his view, processes of the same kind have produced the Kuen Lun in Asia and the Harz and the Teutoburger Forest in Europe. They work with diminished powers in the European areas, but the principles involved are the same. Both in Europe and in Asia the old material has been shaped by the younger bursting and breaking ground-folds. In both every vertical elevation is the effect of an extensive tangential movement.

On this point I venture to advance some considerations of my own, as I have personal knowledge of this subject. The region of the Variscan horsts is indeed small in comparison with Eurasia, but the investigation of its internal structure has advanced possibly further than in any other of the older parts of Eurasia. Though the so-called Hercynian or Variscan horsts, to which I wish especially to refer, belong to the oldest fields of geological investigation, yet recent years have brought a complete change of our views regarding them and a better understanding of their crystalline basement complex.

The more profound our insight into the texture and tissues of a single branch, the better is our understanding of the growth of the whole tree. If we are told that Europe is to be explained by Asia, it is also true that Europe can contribute to the understanding of the main problems of Asia.

As is well known, the horsts, *i.e.* the Bohemian massif, the Harz, the Black Forest, the Vosges, the Central Plateau of France, and the Armorican Peninsula are fragments of the older Variscan and Armorican Arcs, and their actual outlines are quite independent of the fold-trends. The boundaries of the horsts cut across the lines of the old plan and are autonomous in direction. Recent investigations have brought evidence that the original Variscan mountain chain, of which now only scanty remains are left, was once not inferior in size and extension to the Alps of to-day, which are more completely preserved. Indeed, an additional important structural division was joined to the Variscan chain, of which there exists no corresponding equivalent in the Alps. Only the main features can here be briefly indicated.[1]

If we reconstruct from the existing horsts the trend-lines of the Variscan chains, of which the horsts are fragments, it can be shown that only a broad belt to the N. is comparable with the Alps. It is less than half the breadth of the whole structure, and lies between the outer zone in the coalfields of Westphalia and a line near the southern slope of the Erzgebirge. This belt consists of a true folded mountain chain or "orogen," exactly like the Alpine chain. Southwards from the outer border to the interior, the depth from which the outcrop has been lifted increases, and the degree of metamorphism is intensified. The outermost zone, approximately corresponding to the Alpine Flysch-zone, contains the well-known, extensive flat overthrusts of the Belgian and French Carboniferous. The next zone to the S. comprises the early Paleozoic sediments of the Rhenish Mountains and of the Harz; and Kossmat has added his view of the occurrence there of a huge folded overthrust to the known instances of far-reaching thrust-movements in

[1] *Cf.* F. E. Suess, *Intrusionstektonik und Wandertektonik im variszischen Grundgebirge* (1926).

the Taunus near Nauheim, and in the northern part of the Harz. He has confirmed what was expected in the region of Dill and Lahn near Marburg, on the eastern border of the Rhenish mass, from the close association of different facies of Silurian and Devonian sediments. The third zone has been pushed forward against the second zone. It is characterized by the predominance of the crystalline rocks; and there is overwhelming evidence that it consists of a system of overthrust sheets and of blocks piled up and driven northward. The core and the foundation is formed by the gneiss arches of the Saxon Erzgebirge, which are now recognized as a system of flat overthrust folds covering the altered cores of granite. The gneisses of the Erzgebirge resemble in their tectonic position and metamorphic structure the Pennine gneiss arches in the Simplon region, and the arched central gneisses of the Tauern with their "Schieferhülle." The gneiss arches of the Erzgebirge preserve the remains of what were once large thrust-blocks of highly crystalline rocks, that were transported from the S. by still more gigantic movements. The largest of these remains is the gneiss region of Münchberg in the western Fichtelgebirge. It is 20 miles (35 km.) long and 12½ miles (20 km.) broad, and its extremities lie upon the gneiss arches of the Erzgebirge exactly as the Silvretta (*i.e.* the fundamental block of the East Alpine Nappes, or Austrids according to Staub) rests on the Pennine Nappes in the Alps.

It may be inferred from the crystalline facies of the rocks that relatively small exposures of crystalline schists in the Spessart and in the northern portions of the Odenwald near Darmstadt also belong to the same zone of metamorphosed thrust-folds. That is all that has been left of a magnificent edifice which, in its former height and extent, was probably not inferior to the Central Alps from the Savoyan summits to the green hills of Styria at the border of the Hungarian Plain.

For various reasons, and especially because of the crystalline facies of the rocks, I am of the opinion that the so-called Saxon Granulitgebirge, south of Dresden, also belongs to masses that have migrated from the S. over the Erzgebirge.

The large blocks of gneiss are evidently derived from a

crystalline region of another kind, that extended S. of the Erzgebirge. This southern tract occupies the whole of the Bohemian massif to beyond the Danube. Nearly the whole of the Black Forest and of the Vosges belongs to it, and the main portion of the French Central Plateau shows a structure of the same type. In the sedimentary complexes of this region, *i.e.* in the early Paleozoic and late pre-Cambrian rocks of Central Bohemia, there exists indeed a pronounced rather close folding with overthrusts; but it is far from being comparable with the overthrusts of Alpine type which dominate the Variscan Arc proper. Nowhere in this region has the folding been pushed to the stage of considerable attenuation and dynamo-metamorphism. Granitic intrusions, however, attain an enormous extension. They are surrounded by crystalline rocks that have suffered katametamorphism, *i.e.* a transformation caused not by stress and tangential movement, but by the influence of high temperature.[1] The strike of the rocks does not follow one or a few prevalent directions. It conforms, on the whole, but with various local irregular sinuosities, to the outlines of the greater granitic batholiths. The metamorphism and bedding of the rocks is evidently correlated with the adjacent granitic masses. Not the folding of the rocks, but the intrusion of the granitic magmas has obviously been the last formative process, and has produced the final and actual features of this wide region. Older tectonic and metamorphic facies have been obliterated through the influence of the intrusions and have been replaced by post-tectonic katametamorphism. For that reason I have called it the "*region of intrusion-tectonics.*"

The non-metamorphosed pre-Cambrian and early Paleozoic sediments of Central Bohemia belong to this region. They are remnants of its cover. Ordovician rocks are intruded over a long distance by the Central Bohemian granite and altered into contact-hornfels. For reasons into which I cannot enter here, I must assume that the sedimentary and igneous rocks of the Paleozoic and the pre-Cambrian of Central Bohemia—shales, sandstones, quartzites, limestones,

[1] The term katametamorphism is here used in the sense of Becke, and not in the exactly opposite sense for which it was proposed by van Hise.—[Ed.]

diabases, porphyries, etc.—are comprised in the kataschists of high-grade metamorphism. Parts of the cover have been overwhelmed by the granitic magma and drowned in it, and have suffered a sub-batholitic metamorphism.

The ascent of the magma was not limited to any special orogenetic phase; it has continued over an enormous period. The date of its beginning is unknown. As has been said, the intrusions have altered the Ordovician near Prague, and at other localities on the border and in the interior of the great granite mass of Central Bohemia. In the Black Forest the granites have penetrated the Culm-measures (Lower Carboniferous). In the Erzgebirge late thrusts have crossed the main thrust-surface and intruded into the zone of metamorphosed roof-structures. The latest tin-bearing bosses have there penetrated even the Permian porphyries.

The Bohemian basement complex is not an Archean block, as was believed when high metamorphism was held to be a significant character of geological age. The unconformities sometimes referred to between the pre-Cambrian (Algonkian) and the supposed Archean are only inferred and have not really been observed. The non-metamorphosed rocks are in some places in direct contact with the granite and show the usual intercalation of the contact-zone. Only in some tracts to the N. do the non-metamorphosed rocks pass gradually with increasing metamorphism into crystalline schists. The early Paleozoic rocks remain separated from the region of katagneisses in the whole extent of the territory from the Bohemian massif as far as the Central Plateau of France.

The portion of the region of "intrusion-tectonics" that belongs to the Bohemian massif is named the Moldanubian block. This has been moved as a large, relatively stiff unit against the series of "blanketing slices" which make up the Erzgebirge. The overthrust sheet of Münchberg, already mentioned, belongs to a part of the block which has been pushed farther.

The Moldanubian complex stands in approximately the same relationship to the folded Variscan region as the Dinarid mass stands to the Alpine structure proper. According to the Alpine structural geologists, Termier, Argand, Staub, etc., the front of the rigid Dinarid complex has over-ridden the

Pennine zone and the enormous pressure has converted the sediments and granites into a series of "blanketing slices." According to Staub's classification, the part pushed forward is now represented by the foundation block of the "Austrid-Nappes." To it belongs the crystalline mass of the Silvretta, and all the crystalline masses to the E. of the Brenner as far as the Hungarian Plain, except the Pennid and Grisonid windows of the Upper Engadine, of the Tauern and of the Semmering near Vienna. The ruins of the great overthrust sheet form towering mountains in the Alps; but in the Variscan ranges they have been removed and only scanty remnants have been left. In both cases the granitic intrusions are "post-tectonic," and have intruded into relatively shallow non-metamorphic fold-mountains. In this respect the Bohemian Paleozoic corresponds to the Mesozoic of the Alps of Bergamo, which have been intruded by the granites of the Adamello. In both the Alps and Variscan Mountains the granites have crossed the surface of principal overthrusts or zone of "roots," and have penetrated into the folded-zone or orogen proper. Thus the granites of the Veltlin and of the Bergeller massif in Switzerland behave like the granites of Karlsbad and Eibenstock in the Erzgebirge. It is to be assumed that the further advance of erosion in the Dinarids would likewise bring to view very extensive granite masses, and the accompanying schists would have dipped into the zone of regional katametamorphism.

In both the Alps and Variscan Mountains the travelling blocks have transported on their back a foreign stratigraphical facies; and the contrast between the Austrid facies of the East Alpine Mesozoic, so rich in limestone, and the monotonous Bundner-Schiefer has some analogy to the contrast between the so-called Bohemian or Hercynian facies of the early Paleozoic and that of the Rhenish facies with prevalent slates in the Ordovician, Gothlandian and Lower Devonian, which are the characteristic rocks of the non-metamorphic Variscan belt.

In both the Alps and Variscan Mountains the orogenetic process has continued for a very long period; notwithstanding it has been outlived by the period of intrusions. In both cases the rising mountain chains have been inundated by

extensive transgressions, which seemingly divide the folding process into two phases. In the Variscan Mountains the widespread unconformity of the Culm or Dinantian overlaps the various deeply eroded elements, and its material consists in great measure of debris derived from the crystalline cores of the chain. In the Alps the Upper Cretaceous or Gosau beds lie unconformably upon the folds of the older phase. But in both cases the transgressions have no bearing on the orogenetic process itself. They are surely grand phenomena that extended over a great part of the earth's surface, although an adequate explanation is still wanting.

We may consider the Variscan chain, as well as the Alps, as continental-border-mountain-ranges. The so-called geosynclines, with their massive sedimentary sequence, correspond in the one case with comprehensive series of the schistes lustrés of the Pennine Alps ; in the other with the shales of the Rhenish zone. These sediments represent the filling of the foredeep, that migrates in front of the thrust block and becomes itself over-ridden during the orogenetic process.

Another imposing and very remarkable phenomenon in the foundation of the European Altaids can only be briefly mentioned here. It has been shown elsewhere that the Moldanubian complex is thrust eastward over another entirely different structure which is called the Moravo-Silesian Mountain range. The boundary line between both complexes runs through the eastern borderland of the Bohemian massif from the Silesian plain south of Breslau almost as far as to the Danube W. of Vienna, over a distance of 150 miles (250 km.).

The Moravo-Silesian range is a true fold-range of Alpine type, with blanketed sheets of crystalline schists over gneiss cores. The distance to which the sheets have been transported is here probably even greater than in the Alps, for both the regions brought into contact are not only thoroughly different in structure, but also belong to different magmatic provinces.

The thrust-plane is accompanied by zones of deep lamination with development of real mica-schists by shearing. Nevertheless, the boundary line is quite definite and undivided. It is not crossed by any igneous boss or dyke at

all. The wholly unexpected discovery of this remarkable system can hardly be brought into intelligible relation with the known general plan of the Variscan Arc.

As may be inferred from the preceding, the European Altaids are composed of very different elements. The middle region is that of the intrusion-tectonics structure. On the N. this region is attached to the Variscan fold-zone, and on the E. to the Moravo-Silesian fold-zone.

The main portion of the French Central Plateau belongs to the intrusion-tectonic zone, with large granitic batholiths and with katametamorphism. But, adjoining it on the W., beyond the great fault of Argentat, occurs a fragment with a foreign structure consisting of gneiss arches with different kinds of metamorphic "schists and phyllite." Its tectonic relation is not yet understood.[1]

I lay much stress on the general significance of the intrusion-tectonics. As stated previously, the intrusion-tectonic offers some characteristic features where the exposures show the deeper horizons. The lack of any general strike stands in obvious causal connection with the great extension of the batholiths and the post-tectonic crystallization of the schists with the mineralogical constituents of the katametamorphism. No trace of a crystalline axis is there discernible. The intrusion-tectonic belt not only exceeds in breadth any orogenetic zone, but also occupies large tracts outside the true mountain belts. To it belong the whole southern part of the Central Plateau and the West Alpine autochthonous massifs, from the St. Gothard and Mont Blanc as far as the Mercantour. Moreover, the Cor-Sardinian mass and great portions of the Iberian Meseta are likely to exhibit the same features. The observations on the Variscan horsts point to the probability that in Spain also great structural intricacies remain to be revealed.

Further examples of this kind of structure can be found in many an extensive region of crystalline schists, of course with many individual variations. For each region shows the peculiar features that correspond to its individual history.

[1] Mouret, *Bull. Soc. géol. Fr.*, XXVI (1898), p. 601; *Bull. Serv. Carte géol. Fr.*, XI (1899), p. 1; *C.R. Acad. Sci. Paris* (1917), p. 822.

Finland may be quoted as the best-known example of extensive reaction between the general widespread magmatic substratum and the covering " sclerosphere." There, too, in spite of manifold dislocations and certain fold-trends that run for some distance, a prevalent and dominating orogenetic strike is lacking. The complexes that are relatively less disturbed have dipped into the zone of regional katametamorphism with katacrystallization in a broader sense. This zone must be regarded as ubiquitous in the earth's crust at no extreme depth. Sederholm has already emphasized the differences of metamorphism between Finland and the Alps, which latter are characterized by the abundance of chloritic and sericitic phyllites and gneisses.

The process of metamorphism and magmatic fusion in Fennoscandia was not confined to one epoch. Periods of far-reaching denudation, that cut down to the crystalline substratum, were intercalated between the repeatedly revived phases of " Anatexis " (Sederholm).

Similar structures are certainly widespread in the Canadian Protaxis. William J. Miller, referring especially to the Grenville series in the Adirondack Mountains, has recently called attention to the fact that the trend in the old schists has no relation to folding, and that the deformation may reasonably be explained as " a direct result of magmatic intrusion or injection accompanied by not more than moderate compressive forces." According to these and other similar statements made by him,[1] I am inclined to take it for granted that in the Canadian basement complex, as well as in other supposed Archean regions, intrusion-tectonics play no inconsiderable part.

We may conclude from the known data of different regions that in any crystalline complex careful discrimination should be made between folded structures developed by tangential pressure and those accompanied by extensive magmatic intrusions ; and that in any attempt to work out the geological structure of metamorphic territories, careful study of the so-called crystalline facies or the type of metamorphism is indispensable.

[1] W. J. Miller, *Bull. Geol. Soc. Amer.*, XXXIV (1923), p. 679.

Thus the experiences obtained from one of the supposed branches of the great Eurasian mountain system may teach us how many different kinds of structure may still be unrevealed in the large and little-known mountain areas, and warn us to be cautious in the interpretation of trend-lines in the pre-Carboniferous districts of Central Asia. We are justified in assuming as highly probable, that large portions of the metamorphosed regions in Asia do not belong to true fold-mountains or orogens, but that they will show the features of intrusion-tectonics. That is suggested by the frequency and extent of the granitic masses. I give as an example the reports of Berkey and Morris relative to the large batholith in Mongolia, of which the outliers even approach Peking.

As is shown in the Bohemian massif, in regions of this type non-metamorphic rocks and rocks of high-grade katametamorphism, both of the same age, may appear at quite short distances from each other. I am inclined to consider it not impossible that some of the crystalline schists in the Altaid region of Suess may have to be raised in the scale of the Paleozoic strata as high as the Lower Carboniferous (Mississippian).

The Moldanubian block and the other fields of intrusion-tectonics in the European horsts represent one gigantic chip splintered from the roof above the " Sal " and pushed forward by great tangential forces. During the movement it has proved resistant to true folding, and remained relatively rigid; but that has not prevented its reaction to powerful tangential thrusts. Sliding movements of an earlier period, perhaps contemporaneous with the folding of the outer sedimentary arc, have produced intercalations of certain types of micæous gneisses and mica-schists in the deeper interior parts of the block. Movements of later periods are preserved in the form of thrust-planes, mostly accompanied by zones of foliation and phyllonites,[1] diaphtorites,[2] and mylonites.

[1] Rocks of different origins from true phyllites, which have acquired the mineralogical and textural characters of phyllites by stress at lower temperature.—[Ed.]

[2] This name was given by Becke to rocks in which constituents have been replaced by mineral species characteristic of a less extreme metamorphism, such as biotite replaced by chlorite, or orthoclase by quartz and mica.—[Ed.]

To this younger phase belong the great overthrusts near St. Etienne in the Central Plateau and others described by Termier,[1] and the flat fault-thrust with broad zones of mylonite in the southern Black Forest and in the Vosges (Bubnoff,[2] Cohen, Young,[3] etc.). They are themselves traversed by the latest granitic intrusions.

We are fully justified in considering the transgression of the terrestrial Upper Pennsylvanian (Stephanian) and the Permian (Rotliegendes) as the final stage of the main orogenetic process, although the magmas continued to rise as porphyritic effusions. In later periods the regions were still exposed to the action of tangential forces from different directions.

Certain prevailing systems may be distinguished in these later periods :—

1. The *Rhine* direction ; 2. The direction of the *Erzgebirgian* trough ; and 3. The system of the so-called *Karpinskian* or *Asiatic* direction. The Rhenish system is irregularly distributed, and apparently signifies a " breaking " of western Europe N. of the Iberian Peninsula against the Atlantic. Its most prominent feature, the Rift Valley of the Rhine (Rheingraben), has obviously been produced by tension and disruption of the superficial crust, which has occasionally given access to the ascending magma in volcanic vents such as that of the Kaiserstuhl. Its diminished and deflected continuation can be followed northward through the Leine Valley near Göttingen to the western slope of the Harz Mountains. It is accompanied by the more extensive eruptions of the Vogelsberg and the neighbourhood of Kassel. Approximately parallel to this great shattered zone is the broader, and much younger, belt of volcanoes that traverses the Central Plateau of France from the Allier Valley southward and attains the Mediterranean coast near Agde.

The second system, that of the Erzgebirge trough, also includes dislocations of different ages. Its direction is W.S.W. The great fault in the southern slope of the Erzgebirge and the adjoining trench, from which the great effusive masses of

[1] *C.R. Congr. Géol.* (1923), p. 585.
[2] *N. Jahr. Min., B.B.*, XLV (1921).
[3] *C.R. Acad. Sci. Paris* (1922), p. 1377.

the Bohemian Mittelgebirge were extruded, are both Miocene. The shatter-zone continues below the Mesozoic cover of the Swabian Plateau, as is revealed by various Miocene eruptions. Among these are the large explosive vent of Ries near Nordlingen, the group of the tiny so-called embryo volcanoes south of Stuttgart, and further on the Hegau volcanoes to the south of the Black Forest. Numerous other eruptions of Miocene age have made their appearance through other shatter-zones of most irregular distribution.

The third system we have to consider especially. It penetrates intimately the structures of the whole of western Europe from Scania to the Pyrenees; how conspicuously its general trend to the N.W. and W.N.W. becomes visible on some boundary lines of the horsts has often been emphasized; for instance, at the boundary of the Sudeten mountains S. of Breslau, on both sides of the Thüringer Forest, at the slope of the Fichtelgebirge as far as N. of Regensburg, at the minor horsts of Central Germany up to the Teutoburger Forest, at the south-western border of the Central Plateau of France and in the Pyrenees themselves.

It is well known that Suess comprised this system under the name Asiatic lines or Karpinski lines, because he recognized a connection between them and some extensive dislocations that come from Asia, traverse the Caspian Sea, and apparently continue through the W.N.W. dislocations of the Donetz basin and to the mountains of Sandomir in Poland. Thus they pass without perceptible demarcation into the European system of a similar trend.

There is ample evidence that this Asiatic system of faults in Europe is produced by tangential compression acting in general from N.E. to S.W. One of the most remarkable facts is the entire lack of volcanic occurrences on these lines. Even the Pyrenees, which follow the same direction, are remarkably poor in younger volcanic rocks, compared with some other Kainozoic chains.

Evidence of horizontal thrusts have long been known at various localities. The most frequently cited is the thrust of granite over Jurassic on the great Lausitz-fault at the slope of the Riesengebirge on the Saxon-Bohemian boundary. Analogous to it are the parallel overthrusts at several

localities along the Danube between Regensburg and the Austrian boundary, where granite or Permian rocks overlie Jurassic and Cretaceous sediments.

Movements of the same tendency but of far greater extension are recognizable in the division of the so-called Sudeten mountains into a series of thrust-blocks limited by approximately straight lines. That the blocks must have been brought into their present position by great horizontal movements is proved by the difference of structure in each of them. The innermost block contains the large granitic masses and crystalline schists of the Riesengebirge and the Isergebirge. The second or middle block contains the Paleozoic of the Boberkatzbachgebirge, overlain by the overthrust gneiss masses of the Eulengebirge and the Spieglitzer Schneegebirge; these masses are the remains, and give evidence of a far-reaching overthrust structure, previous to the partition of the second block into thrust-blocks with a north-westerly direction. The third block consists of the crystalline and Paleozoic hills in the Silesian Plain.

The youth of this straight-lined partition of the folded range is proved by the irregularities of its relief. In this region stands the highest mountain of the Bohemian massif, the granitic Schneekoppe (5260 ft.), near the Cretaceous Heuscheuer (3639 ft.) and the gneissose Spieglitzer Schneeberg, and between these mountains lies the flat Permian basin of Braunau. We find here also confirmation of the fact that in the outer relief of the earth's crust, the greatest heights and depths are produced by relatively young tectonic movements; and it is uncertain to what degree the heights in the southern Bohemian massif, and perhaps in the Black Forest also, are due to vertical elevation in consequence of the Cretaceous and post-Cretaceous tangential compression.

Besides the larger fractures, uplifts and fault-troughs, we find widespread evidence of dynamic alteration of the rocks due to regional tangential compression. In any part of this vast region, where investigation has advanced sufficiently, innumerable smaller dislocations are found to exist. Thus the detailed maps of the Bohemian Paleozoic of the Thuringian fold-zone, as well as of the unfolded Mesozoic basin of Swabia, show a lattice of straight fault-lines with a great prevalence

of the north-westerly direction, and crossed by a comparatively small number of faults with other trends.

The well-known quartz-ridge called the great "Pfahl" runs with astonishing straightness for more than 100 miles (160 km.) from Amberg in Bavaria to beyond the Austrian frontier. It has been produced by the filling of a long cleft with material derived from the decomposition of crushed felspars into quartz and sericite. The long rupture is accompanied by a broad band of mylonites and thinly foliated sericitic schists, alteration products due to the intense shearing along the disruption.

Overwhelming evidence of the enormous pressure suffered by the whole of the mountain block is afforded by the innumerable fissures and joint-plains and by a minute foliation that becomes visible on fractures. It traverses in straight parallel directions all kinds of crystalline rocks, granites, and gneisses, not only in the vicinity of the great fault, but also far off from it over almost the whole south-western part of the massif.

The unilateral push from the N.E. which is distinctly marked by the prevailing number of N.W. to S.E. faults, leads us to infer that this area has not been affected by crustal contraction but by pressures operating from outside. Deviations are produced by the irregularities of the older structure.

Suess has emphasized that this system of faults is connected with another that was described by Karpinski, and traverses, on lines that are approximately parallel, the main part of southern Russia. It comes from the Alai mountains in Asia; its continuation forms the anticline of the Mangishlak Peninsula in the Caspian Sea. Along the same line, farther on, lie the foldings of the Carboniferous deposits of the Donetz. They are on both sides accompanied by a broad belt of parallel subsidiary features, which continues to the mountains of Sandomir in Poland, and there reach the Middle European System. The assumption is well justified that all these lines, as they have a common trend for enormous distances, are of common origin. If we admit that the Asiatic folded blocks are produced by a great tangential push related to the southward creep of the enormous crustal sheet, we must also consider the north-western fault-system

of western Europe as the deflected and diminished effect of the same process.

Let us now return to Argand's analysis. He divides the structure of western Europe into seven ground-folds belonging to the Alpine Cycle. The first of them consists, according to him, of the ancient Helvetian massifs in the Alps, from St. Gothard to the Mercantour. In my opinion these masses ought to be separated from the true horsts. They may be built up of the same ancient material, but their elevation is due to other causes, and is not only incomparably greater, but also younger than that of the horsts. Only the Alpine thrust, caused by the advance of the African continent, has been powerful enough to raise the basement complex to the lofty summits of Mont Blanc and the Jungfrau.

The north-western dislocations or Variscan lines are not recognizable in the Alps themselves. In the region of the Helvetian massifs the Variscan lines may have been effaced by the Alpine movement, while the crystalline basement complex of the so-called East-Alpine Nappes or Austrids belongs to another continental complex, as Argand himself assumes.

The other ground-folds—Nos. 2 to 5 of Argand—have raised the principal horsts, which he has arranged according to the distribution of the main elevations, as follows :—

2. The French Central Plateau and the broad domes of the Vosges and the Black Forest.

3. The Armorican massif.

4. Cornwall in England, the Ardennes and the Rhenish Paleozoic mountains.

5. The Teutoburger Forest, the Harz, the north-eastern part of the Bohemian massif, the Silesian mountains, and the Lysa Gora (mountains of Sandomir) with the intercalated troughs. This ground-fold sinks rapidly below the Oligocene, Neogene, and Quaternary of the North German Plain, where deep borings have revealed the persistence of structures similar to that of the neighbouring horsts.

6. The flat ridges of the smoothly vaulted Upper Cretaceous and Kainozoic in Denmark. Its great radius of curvature is attributed to the stiffness of the underlying rocks that belong either to the Baltic Shield or to a hidden branch of the Caledonian Chains.

7. Scania and Bornholm are considered as a seventh zone. Their great radius of curvature is referred to the stiffness of the pre-Paleozoic basement that has been worked into this ground-fold.

8. The broad elevation of southern Sweden is considered as possibly an eighth zone.

To this conception we may remark first that these assumed ground-folds are internally divided into strips by approximately parallel faults or overthrusts. It has been stated above that these dividing lines are of different ages. One of the most prominent lines between the fold of the Erzgebirge and the granitic masses and schists of the Lausitz is of pre-Permian age. It separates two very different structures, and it is obviously of great importance.

The partition of the eroded Variscan structures must have started comparatively soon after the close of the folding process, that is about late Carboniferous time. It has persisted, of course, with many irregularities and interruptions, at least into the early Kainozoic. Naturally, it is the younger post-Cretaceous series of movements which has formed the main features of the actual morphology and the ridges and basins of Argand's ground-folds. It would be hardly possible to refer their development to one definite cycle of mountain-building. They are also related to the development of the Asiatic folded blocks or ground-folds, so far as has been ascertained from repeated movements on great fault-lines radiating outward from the bulk of the continent.

Of course, the temporary occurrences of strainings and crushings in other directions, especially those of the Erzgebirge and Rhenish trends, participate in a very conspicuous manner in the determination of modern morphology.

Concluding Remarks.—It is difficult to establish definite connecting lines between the pre-Permian structures that have been distinguished as the European and Asiatic Altaids. What is called the Variscan range contains large crust-sheets of the type of the intrusion-tectonics. This range is cut off on the E. and thrust over a structure of Alpine type—the so-called Moravo-Silesian Chain—of which the principal trend is from N.N.E. to S.S.W. We can expect that the pre-Permian basement complex of Central Asia will also contain a great

variety of structures, and that a considerable portion of them will have to be explained as examples of intrusion-tectonics. In such regions with abundant crystalline rocks the determination of regional structural connections, and the age of the mountain chains cannot be based on the mere trend-lines without special investigation of the position and the crystalline facies of the schists. Very likely, in large areas, the trend-lines will have no relation to the true fold ranges, as is the case in the Canadian Protaxis and elsewhere.

In Europe, as in Asia, the old structures have been overwhelmed by the younger tangential movement, and here as in many parts of Central Asia the actual morphology is related to transverse disturbances sometimes of great extent.

The history of the European-folded blocks has been, of course, in some respects different from that of the Asiatic blocks. The steep fault-scarps of the horst-ridges have been better preserved in the almost continuous desert climates of Central Asia than in the humid climate of Europe. These areas have also been traversed by peneplanes of different ages, and especially by planes of wave-erosion, due to the repeated invasions of the Miocene and older Kainozoic Sea.

The mobility of the earth's crust is not throughout restricted to the relatively narrow belt of the Kainozoic orogens. The large creeping sheet of the Asiatic continent is crushed and distorted in a very considerable degree. The " dry overthrusts " which occur in the interior of the continent arise from the same general impulse as the more striking chains of the new pliable strata of the Tethys. The " continental border chains," above all, have elevated the thickest and most complete sedimentary series.

The unifying attribute of the Altaids is accordingly their common pre-Upper Carboniferous or pre-Permian age, and the unconformable cover of mostly late Carboniferous or Permian sediments. But they may contain structures of various trends and of various ages. The transgressions of the Upper Carboniferous and the Permian Seas extend over great parts of Asia, of Europe, of Northern Africa and North America ; and it is observed as well in the mountain chains of the Alps and of the Atlas, as over the forelands of Variscan age. The nearly contemporaneous exposure, over so great a

portion of the earth's crust, of structures of different ages cannot be referred to processes that are strictly orogenetic. Like the great marine transgressions of the Upper Jurassic and of the Upper Cretaceous, this phenomenon is not dependent on the processes of mountain-building proper. It is true, the older and the younger orogens have their own stratigraphy, which is different from that in the forelands. Nevertheless, even in the more ample stratigraphical sequence of the orogens one can observe indications of the general rising and sinking of the ocean-level. In the Alps, for instance, the coals of the Carnian (Lunz sandstone) are the equivalent of the coals of the extra-Alpine Keuper. The rising of the sea during the Upper Trias, Rhætic and Lias is seen in the Alps as well as in Germany. The transgression of the Gosau beds in the Alps corresponds to the general Upper Cretaceous transgression.

Phenomena of this kind, to which also belongs the great transgression that separates the Altaids from the younger mountain systems, must be connected with events of a more universal character; such as the creeping of continental masses in the sense of Wegener's hypothesis, or variations in the form of the hydrosphere or other still unknown causes.

CHAPTER III

CONTRIBUTION TO THE STRATIGRAPHY AND TECTONICS OF THE IRANIAN RANGES [1]

By Dr. H. de Böckh, Dr. G. M. Lees, and F. D. S. Richardson

PREFACE

Sir John Cadman, Chairman of the Anglo-Persian Oil Company, gave me the opportunity of studying in the winter seasons 1923-24 and 1924-25, the geological conditions of the Concession areas of the Company. I had the pleasure of the company, during my journey, of Mr. S. Lister James, the Chief Geologist of the Company, and Dr. G. M. Lees, and during a part of it of Mr. F. D. S. Richardson.

The result of these journeys was a geological synthesis of the W. and S.W. parts of Persia, where I could recognize the Foreland, the autochthonous folded and sheared zone, followed by a zone of nappes, and then the Median Mass.

In 1925-26 I had the honour of leading the party which carried out the geological survey work for the Turkish Petroleum Company, Ltd., in Iraq. In the course of this work I visited large areas, being accompanied for part of the time by M. Viennot, Professor A. Trowbridge, and Mr. J. R. Bourchier.

In June, 1926, I undertook, at the request of Sir John Cadman, a journey along the Qasr-i-Shirin-Kermanshah-Hamadan road to Kasvin and Teheran, and then back through Semnan and Qum.

[1] Paper read on the 11th of September, 1928, at the meeting of the British Association for the Advancement of Science, and published by permission of the Chairman and Directors of the Anglo-Persian Oil Co., Ltd.

In 1925-26 Messrs. F. D. S. Richardson and Franklin made a study between Dashti and Lingeh, and Messrs. Lees and K. Washington Gray studied the Oman range, on which Dr. Lees has published a paper. In the same year he also made a traverse of the Bakhtiari Road across the Zagros ranges from Masjid-i-Sulaiman (Maidan-i-Naftun) via Malamir to Isfahan. It was a great pleasure for me when Professor J. W. Gregory invited me to give a paper on the geology and tectonics of the Iranian ranges. The results of my above-mentioned journeys and the studies of Dr. G. M. Lees and Mr. F. D. S. Richardson, supplemented by the publications of previous workers such as Loftus, de Morgan, Douvillé, Stahl, Fischer, Gregory, Pilgrim, Pascoe, and Tipper, and by the discoveries of other A.P.O.C. geologists, have given the evidence used in this paper, and I am very much indebted to Sir John Cadman for his permission to publish the principal results obtained during the extensive geological work carried out on behalf of the Anglo-Persian Oil Company, Ltd.

I have written this paper in collaboration with Dr. G. M. Lees and Mr. F. D. S. Richardson, who have been always enthusiastic collaborators. Dr. Lees has written the part on the Oman range; the other parts have been worked out chiefly by Mr. F. D. S. Richardson and myself.

The collected fossils and rocks form a large mass of material, which has not yet been studied in detail. The time at our disposal for the preparation of this paper was only two months, and much of it has been occupied with other urgent work, but at the same time I feel that the publication of much new evidence will be of great interest to the geological world. The paper is a report on our knowledge as it stands, which will be enlarged when the collections are *studied in detail;* but the main lines laid down in 1924 and 1925 will, I hope, not be changed.

To enable us to solve certain questions we had to call in the kind assistance of Dr. Douglas, Mr. W. B. R. King, and Dr. Spath, and we are much indebted to them for the help they have given us in the determination of some of our fossils.

H. DE BÖCKH.

INTRODUCTION

More and more clearly develops the knowledge of the Mediterranean Mesozoic and Kainozoic ranges. The Alps were the centre from which our knowledge began to spread. It has been a long course of development, and we have learned much. We have learned to recognize facts not dreamed of before, but as far as the explanation of mountain-building movements is concerned, we have only reached a stage of more or less brilliant hypotheses—some of them are brilliant working hypotheses indeed—but yet hypotheses only. It is a comparatively small part of the Mediterranean ranges with which we shall deal—the Iranian ranges of Iraq, Kurdistan, and Persia only, and a part of Central Persia—but it is a link in the complete synthesis of Asia.

As in other orogens of the world, so here, too, we can make the following divisions :—

In Mesopotamia and westwards of it, then to the W. of the Tigris and Shatt-el-Arab down to the Persian Gulf, and S.W. and S. of the Gulf until we reach the Oman ranges, there lies the Arabian Table, a Foreland, in this case a typical *Aire Continentale* (Haug). Going eastwards, or, in the more southerly areas, northwards, we reach the Autochthonous Folded Zone. Near Shamil and Minab this autochthonous folded zone turns sharply to the S.S.E., and then, in the environs of Jask, again eastwards to form the Makran coast. This belt is much broader in the northern areas and in the territories adjacent to the Persian Gulf than along the Makran coast. Crossing this zone and approaching the higher ranges, we find stronger and stronger folding until we reach a zone where in many places shearing occurs, and then a zone with typical nappes. They have been traced from the surroundings of Kermanshah to the Zindon range near Minab. In the Zindon range there is a sharp bend in the trend of the nappes, which swing forward forming a " garland," and here ends the territory examined by us; but from Blanford's and Tipper's descriptions it is clear that some of the same nappes as in the Zindon ranges are present between the 60th and 61st degrees of E. longitude, in the surroundings of Jeh.

Behind the napped zone follows a typical Zwischengebirge

or Zwischenmasse, which we shall call the Median Mass. This forms the Iranian Highland.

The Oman range behaves strangely. It is difficult to understand, and it is only recently that the work of Messrs. Lees and Gray has thrown new light on it. In it earlier Paleozoic limestones are separated by a slight unconformity from the Permian. Trias and Jura are frequent. Strong pre-Gosau movements have been recognized. Maastrichtian is transgressive and then the Eocene too. They come over eroded surfaces. The present morphology of the mountains was developed in the Pliocene. The pre-Gosau movements are only very feeble in the Zagros, if indeed they are present at all; movement occurred in some zones during the Senonian. The Oman range is like a garland, an outer arc, but Kober thinks that it is a branching of the African branch of the Mesoids.

We know too little about the parts of Persia to the E. of Dasht-i-Lut, and about Baluchistan and Afghanistan to answer certain questions.

The above big tectonic units will be dealt with in the following order :—

We use the following nomenclature :—

The Foreland is the stable part in front of the orogen towards which the folding is directed. This term has been used by Swiss geologists to include everything in front of the Pennine Nappes. We use it in the sense of Suess.

The term Foreland is used without prejudice to the question whether the Foreland has pushed under towards the orogen, or whether the orogen has been moved over towards the Foreland.

Recently the term Rückland[1] has been introduced in

[1] The term Hinderland has been used as an English equivalent.

connection with the idea that Africa has been moving northwards, pushing the Alps in front of it; but even Staub admits in his recent book, *Der Bewegungsmechanismus der Erde*, that the Rückland can become a Foreland, and the Foreland a Rückland, when followed along the strike of an orogen.

It seems to us that such changes are connected with the presence or absence of a Median Mass. When, as in the case of the Carpathians, a Median Mass is present, the branches of the orogen show distinctly an outward movement from the Median Mass over the Forelands. It is the same in the case of the Iranian ranges. In the Alps no Median Mass is found, and here the direction of movement of the southern Alps is a highly controversial question. The Median Mass is a more or less stable part surrounded by a folded and napped zone, the orogen. In some cases it lies between two branches of an orogen, as for instance, between the Elburz and the S.W. Iranian ranges; in other cases a part of it is surrounded by different portions of one branch, as in the case of the region surrounded by the eastern Carpathians. The Median Mass may be formed by parts of one or more older orogens, and it may include parts of older Median Masses too.

We prefer the term Median Mass, because it expresses more precisely the general conception; the term Zwischengebirge is, for instance, not an apt description of the Caribbean Sea or the Pannonian (Hungarian) Basin. Both are Median Masses, but the one is covered by the sea, and the other is in the main a plain.

PART I. THE FORELAND

To the west of the Euphrates and of the Persian Gulf extends a slowly rising dissected country, formed for miles by nearly horizontal beds, which range from the Cretaceous upwards. Only very gentle folding and warping can be seen; thus, for instance, at Anah an E.W. striking gentle fold can be observed, whereas in the neighbourhood of Hit and Ramadi N.W. to S.E. trends prevail.

In the Jebel Sanam, S. of Basra, old rocks project from below the Kainozoic cover. These rocks show a great re-

semblance to the Cambrian rocks of the Persian Gulf, and the tectonics suggest the presence of a salt plug. We shall deal later with the Cambrian rocks of the Persian Gulf.

At Bahrain a N. to S. trend can be seen, with very gentle dips, and it is only when we reach Oman that the foreland character changes, and we encounter here the Oman range, a typical orogen, apparently a virgation of the West Iranian ranges.

It is not within the scope of this paper to discuss Arabia and its tectonics, and we shall confine ourselves to a few remarks. For further details we refer to Krenkel's *Geologie Afrikas*.

Arabia, excluding for the moment the Oman ranges, is a great rectangular tableland, which has shown since Cambrian times no orogenetic movements. It is separated from the West Iranian ranges by Mesopotamia and its continuation, the Persian Gulf. Parallel to this sunken strip lies, on the other side of Arabia, the part of the " Great Rift Valley " occupied by the Red Sea. These two low-lying strips impress on Arabia a N.W. to S.E. orientation. At the S. end of the Dead Sea between Wadi Saramuj and Zerka Main, Cambrian rocks unconformably overlie a massive conglomerate composed entirely of a great variety of crystalline rocks, penetrated by innumerable dykes. Farther S., granite, granite-gneiss, and schists form the basement. Locally, ancient volcanic rocks are recorded, and in Hejaz Kober recognized three phrases of intrusive rocks. In some regions immediately adjoining Arabia, *e.g.* in Eritrea, an older series of schists and gneisses, and a younger series of phyllites, slaty shales, quartzites, crystalline limestones, and locally massive conglomerates can be observed. The rocks are intensely compressed, and dip at high angles. Intrusive rocks—granite, syenite, etc., occupy great areas. The strike varies from N.-S. to N.N.E-S.S.W. The same strike can be observed in the old rocks of the whole Red Sea area. It is the old grain of Arabia.

Throughout Paleozoic times, Arabia was connected with the African continent, and it is a noteworthy feature that in S. Arabia the marine transgressions of the Mesozoics come from the direction of the present Indian Ocean. The most

northerly known extension of the Triassic Sea is in Eritrea, and Triassic rocks appear again in Oman. The shore-line probably struck north-eastwards from Eritrea, and it is therefore possible that further examination may prove the presence of Trias in Arabia. The Jurassic and Lower Cretaceous Seas had their northerly limit in Eritrea. Philby collected Jurassic fossils in Central Arabia near Riyadh, and in Aden and Makalla, and Jurassic is known in Oman, but is absent from Murbat on the S. Arabian coast and from Sokotra. The fauna of the Jurassic near Riyadh shows very little or no affinity to the Jurassic of Syria and Sinai, but is related to that of Cutch, Somaliland, and East Africa, and indicates, as we know, a Sequanian-Kimmeridgian age. So we see here, in the southern part, the signs of Mesozoic transgression. The case is different in Syria, Palestine, and Hejaz; here Paleozoics are known. We have mentioned the Cambrian rocks which occur near the S. end of the Dead Sea. Blanckenhorn mentions from Hejaz, E. of the Tebuk oasis near Shar ul Ghul, dark bituminous siliceous shales containing *Diplograptus*. We do not know whether the Cambrian was connected in the north with the old rocks of the Jebel Sanam and the Cambrian rocks of the Persian Gulf, which we shall describe later, or whether there was a barrier between these deposits. In Palestine one can define a zone not more than 30 miles wide, which contains three shorelines of three separate transgressions, namely Cambrian, Triassic and Jurassic. Messrs. B. K. N. Wyllie, K. A. Campbell, and Dr. G. M. Lees collected from the N.E. corner of the Dead Sea a fossil assemblage of Carnic age. The fauna is a mixture of forms of the fauna of Raibl with others belonging to the German Lettenkohle facies. The collection was studied by Mr. L. R. Cox.

At the S.W. end of the Dead Sea, a salt plug occurs at Jebel Usdum. The salt pierces a series of fresh-water or brackish-water Tertiary beds, and is therefore older than they are. It may be of Triassic to Cretaceous age, but there is a possibility that it may be older. Jebel Usdum is close to the Cambrian shoreline, and Cambrian salt is known in the Persian Gulf. Further investigation is needed to clear up this point.

In Sinai and Eastern Egypt, Carboniferous and Jurassic

shorelines are known, and a Lower Cretaceous shoreline has been determined in N. Sinai. In Syria, Jurassic, from the Lias to the Upper Malm, is well developed, but the highest stages of the Jurassic seem to be absent. The Lower Cretaceous is marine, but the fossiliferous marls are interbedded with carbonaceous sandstones. Then in the Cenomanian is another great transgression, and rocks of the various stages of the Upper Cretaceous, Eocene and Oligocene have a great, but as yet undefined, extension in the Syrian Desert. H. de Böckh found, at the W. end of the Heri Plateau, *Ostrea* cf. *nicaisei* Coq. The thickness of the rocks diminishes rapidly from the Palestine-Syrian folded belt in the direction of the unfolded tableland. The Cretaceous and Kainozoic rocks have, as we have mentioned, a great extension along the E. side of Arabia. Messrs. E. W. Shaw and A. H. Noble collected *Loftusia persica* Carp. and Brady from Wadi Bughar, and Messrs. Chatwin and Pringle determined *L. persica* from a point 40 miles S. of Nahiyah and from Huzumiyat. Messrs. Shaw and Noble found, near the *Loftusia*-bearing rocks, reddish and purple shales which may represent the base of the Eocene, and in Oman, near Char Riyab *Styracoteuthis orientalis* Crick has been found. In the Wadi Hauran *Nummulites gizehensis* Forskal occurs, and M. P. Viennot determined *Nummulites distans* Desh.- *tchichatcheffi* d'Arch. from the Wadi Ukheidr. At Bahrain rocks apparently of Middle Eocene age occur, which consist, according to Pilgrim, of white limestones and chert-bearing marls. Near Anah, Khan Baghdadi, and Haditha, *Nummulites intermedius* d'Arch.- *fichteli* Michelotti occurs in a rubbly limestone, boulders of which are found in a conglomerate, and in the Wadi Khan Baghdadi a conglomerate bed contains *Kuphus*. W. of Anah in the Wadi Hasan, a dolomitic limestone occurs, containing *Lepidocyclina* cf. *raulini* Lem. Douv. Above this follows a dolomitic limestone about 80 ft. thick, parts of which are formed by coral-reefs. The series is overlain by a coarse conglomerate, which has a very variable thickness. This conglomerate is overlain by the Euphrates limestone, which is equivalent to the Burdigalian part of the Asmari limestone. At the N.W. end of Anah, the conglomerate is replaced by red marls. Ainsworth has

described from Anah an *Actæonella*, and, on the basis of his paper, Cretaceous has been recorded from Anah ; but there is no doubt that nothing older than Oligocene is exposed in the neighbourhood. The " *Actæonella* " was doubtless a large *Conus*, which occurs in great numbers in the Lower Miocene there. The above-mentioned conglomerate is without doubt younger than the *Nummulites intermedius-fichteli* beds and represents a break during Aquitanian time. As we shall see, this break is well marked over large areas in northern Iraq and Kurdistan. The Euphrates limestone is overlain by gypsiferous beds, and then follows a formation of reddish marls, reddish sandstones, greenish beds, whitish sandstones, and sandy limestones, which probably represent the Upper Fars and Bakhtiaris. The gypsiferous series contains *Ostrea latimarginata* Vredenburg, a characteristic fossil of the Lower Fars. Further investigations are needed to prove which members of the Lower, Middle, and Upper Fars are represented in the series. Ainsworth has recorded a gypsiferous series N. of Anah, overlying the Euphrates limestone. These deposits can be traced up to Halebiyeh-Zalebiyeh, where the Euphrates cuts through the Jebel el Bishri and down as far as Haiat Heyadiya, S.W. of Najaf. From here to Samawa the Euphrates limestone is exposed, overlapping the Eocene. Mr. James observed a gypsum scarp near Ur. In Jebel Sanam the old rocks are overlain by the gypsiferous series, which is followed by sandy and pebbly beds. Further studies are necessary to establish the exact correlation of these beds. Near Kuwait horizontal beds occur, which have been described in various reports as the Kuwait series, but nothing is known about their exact age. Along this whole Foreland, nothing is known which could be compared with the Pliocene Bakhtiari sediments, and it seems that in Pliocene times the whole area described above was subjected to erosion. The study of the river-terraces and pebble-deposits of the region would profitably occupy the attention of future explorers.

Volcanic rocks, mostly of basaltic type, occupy large areas in the Syrian desert, in the Hejaz and in Central Arabia. Eruptions were of a quiet type, and have not built any large cones. The age of the vulcanicity is uncertain, but it is post-

Eocene, and in places, as in Transjordania, activity continued until very recent times. In S. Arabia, Cretaceous trap rocks are known in the hinterland of Aden, and some of the basic intrusive rocks of Makalla are probably of this age.

PART II. THE AUTOCHTHONOUS FOLDED REGION AND THE ZONE OF SHEARING

Going eastward from the region of the " aire continentale " deposits, we find a considerable thickening of the whole sedimentary series. For example, the Mio-Pliocene series, which was estimated to be not more than 800 ft. thick near Hit, attains a thickness of 13,000 ft. and upwards in the folded region.

Mr. W. R. Macdonald and Dr. J. H. Jones have made a gravity section from Ahwaz, where the first well-pronounced fold appears, westward to Jebel Sanam, where old rocks, dolomites, and quartzitic sandstones crop out (see Pl. I). This section shows a steady decrease of gravity towards the north-east, which is the natural consequence of the fact that in this direction, the younger deposits, which have less specific gravity, thicken. The effect of the Ahwaz fold is shown clearly in this section. The value of gravity is greater there, the natural consequence of the older heavier rocks coming nearer to the surface in the anticline. Westward from it there are indications of a gentle fold, but beyond this everything is quiet and undisturbed. The Ahwaz fold is a long narrow steep-sided anticline.

Going across the strike to the N.E. the intensity of the folding increases, but along the strike the intensity varies greatly. In Iraq a strongly-folded zone, which formed a littoral region in Miocene times, begins at Dohuk and can be followed from there south-easterly to the Diyala River (Ab-i-Shirwan in the upper part). On the left side of this river we find stronger folds pitching down towards the N.W. along a N. to S. line. These folds form a kind of garland, the folds of which pitch down again along an E. to W. line between Dalpari and Qilab, and it is only to the E. of Dizful that stronger folding is once more encountered. On the left side

of the Karun River, E. of Shustar, stronger folding reappears. Hence to the Mishun area the garland-structure is not well-defined, but there is a general N.W. pitch in the region N. of Marmatain, and a suggestion of a garland-form in the mountains near Behbehan.

To the E. and S.E. of Bushire, the Kuh-i-Mund, Kuh-i-Qaleh Dukhtar, and Kuh-i-Gisakan, and the mountains N. of the last-named, all pitch down along a line running slightly E. of N., and a new garland begins; near Khamir the folds swing back to a direction slightly N. of E. and pitch down successively along an E.N.E. line until we reach the Zindon range, which trends N.N.E. to S.S.W.; there, and along the Makran coast, a new garland can be seen.

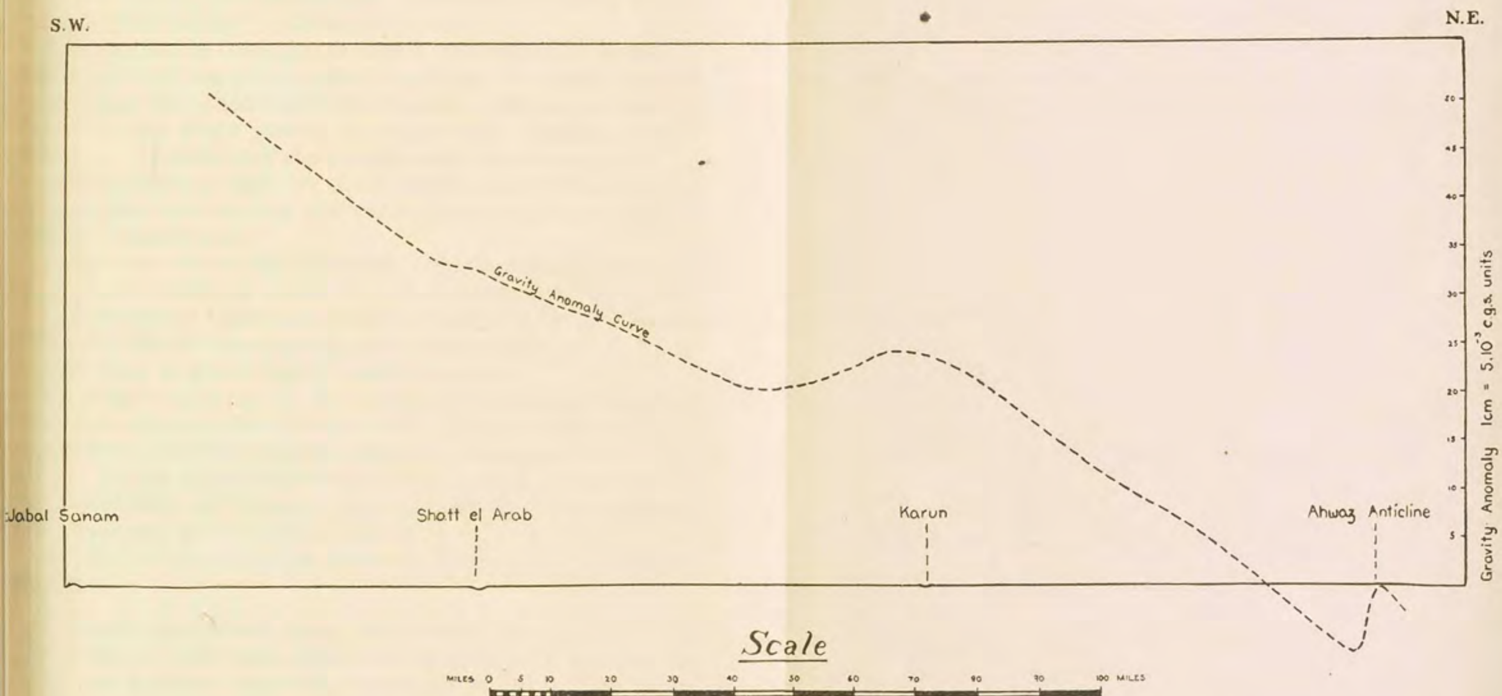
In several places a step-like development can be observed as one crosses the strike. This step-like development was recognized and called the Iranian Ladder in ancient times. The steps express the fact that the folding movements advanced progressively from N.E. to S.W. The most south-westerly ranges are often covered by a great thickness of Upper Fars and Bakhtiari. Then follows a zone in which the Middle and Upper Fars and Bakhtiari have been strongly eroded, and in which a peneplane was formed towards the end of the Pliocene (Pl. IV, fig. 1). Then follows a zone in which the pre-Miocene rocks are widely exposed.

The gentle anticlines which lie in front of the Iranian ranges, and which are still covered by Bakhtiari and other members of the Mio-Pliocene series, occupy a territory which has sunk down in more recent times.

In the Persian Gulf region, a recent breaking down of the littoral territory is clearly marked, and there is no doubt that the Persian Gulf is of very recent origin; Kuh-i-Ginao, Kuh-i-Siah, and Kushk Kuh all show great major faults, and these mountains rise abruptly from the level coastal plain to heights of 5000 to 8000 ft.

On Kharag Island, Bakhtiari deposits have been folded and eroded, and this fresh—or perhaps brackish—water series is unconformably overlain by Pleistocene marine sediments.

The following section (Pl. II) illustrates these facts. Going eastwards from the above-mentioned step, where considerable areas of Lower Fars have been exposed, other steps follow,



GRAVITY ANOMALY CURVE BETWEEN AHWAZ AND JABAL SANAM

AS DETERMINED BY

W. R. MacDONALD, Dr. J H JONES & R. DAVIES

1925

the degree of folding becoming more intense, and plis-faillés develop. Then comes a zone in which no regular anticlines are to be seen, and faulting and thrusting of smaller scale occur. This is the zone where shearing occurred, somewhat as in the Swiss Jura Mountains. Buxtorf has called this a "nappe of shearing"—*Abscheerungsdecke*.

As happened in the Alps, so also in the regions in question, fold after fold has been linked together, the north-eastern folds being older than the south-western. We can, of course, here only lay down general principles and describe general features. To work out the details needs laborious study.

In the following pages we shall describe briefly the deposits forming the two regions, the zone of autochthonous folding and the sheared zone.

PALEOZOIC—From the Paleozoic, only Cambrian is known.[1] Until now Cambrian rocks have been unknown in Persia. The discovery of Cambrian trilobites in the Al Buza Hormuz inlier, the first of them having been found by Dr. G. M. Lees, is, therefore, of great interest and importance.

Dr. Pilgrim and Dr. R. K. Richardson have described the salt occurrences of the Persian Gulf. Pilgrim includes them in his Hormuz series, together with the overlying sedimentary rocks. In his latest publication he considers the salt to be most probably of Triassic age, whereas he attributes the other Hormuz rocks to the Jurassic.

He divides the Hormuz series as follows, in descending sequence :—

4. Purple sandstones, grits, and shales.
3. Volcanic tuffs and agglomerates, generally gypsiferous and often containing fragments of (2). With them are interbedded rhyolitic lava flows.
2. Dolomitic limestones and shales, either black and fetid or yellow, with siliceous veins or concretionary flints, sometimes massive but more often thinly bedded and fissile, often gypsiferous and occasionally with interbedded rhyolitic lava flows.

[1] Graptolites (Diplograptus?) have lately been found by J. V. Harrison and A. H. Taitt at Furgun, 50 miles N. of Bandar Abbas, close to the front of the zone of nappes.

1. Rock salt. This appears to be the basal member of the series. Intrusive rocks of more basic type also occur.

Pilgrim points out that these rocks have a very wide distribution and uniform character. We quote the following lines from Pilgrim (1924), pp. 16-17 :—

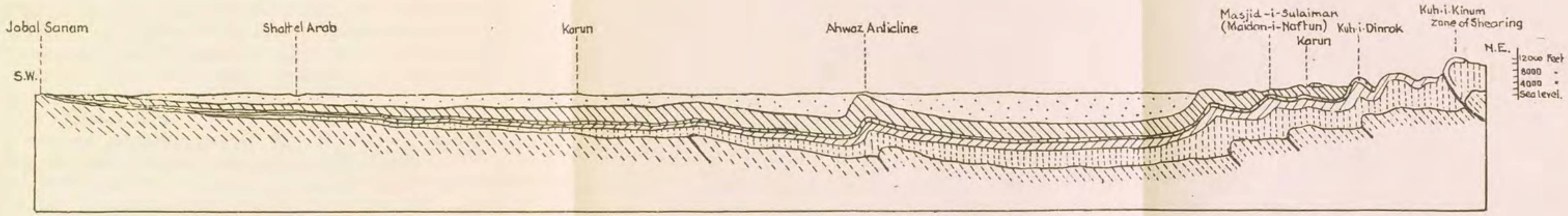
" In spite of this wide distribution, the total area covered by its outcrops is comparatively small, in which respect it forms a striking contrast to every other rock system in Persia. On the mainland its outcrops are roughly circular and rarely occupy an area of more than 20 square miles each. Hence one may conclude that the islands of the Persian Gulf do not represent the exposed portions of a continuous formation, but that if the sea-floor were elevated we should find that the Hormuz series would be confined to comparatively few isolated hilly patches.

" It is a significant fact that we seldom find any one member of the series entirely missing in any outcrop. The rock-salt portion of the series forms an occasional exception, but even so the rock-salt is never found except in association with the other members of the series. When we take these facts into account, along with the general uniformity of character and mineralization which it everywhere presents, it seems impossible to regard it as otherwise than a single unit, even though the period during which it was formed may be a long one."

Many salt-plugs occur as islands in the Persian Gulf or as intrusions on the mainland. They have in general a round or elliptical outline, and the younger rocks are always steeply upturned around the periphery of the salt mass.

The following is a brief description of the salt plugs which we have visited ; the numbers refer to the numbers on the map (Pl. XXIII).

16. Namakdan, Qishm—The salt is intrusive through the Mio-Pliocene series on the western end of the Salakh anticline. The Mio-Pliocene series shows a continuous unconformity around the plug. Traces of unconformity in the Mio-Pliocene series occur all over the island. A low raised beach is turned up steeply on the eastern side of the plug near the shore. Large blocks of a black dolomite and gypsum



DIAGRAMMATIC SECTION FROM KUH-I-KINUM THROUGH MASJID-I-SULAIMAN TO JABAL SANAM.

The part of this section from the Ahwaz Anticline to Jabal Sanam is based on results of Torsion Balance Survey.

Horizontal Scale

Miles 10 5 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 Miles

Bakhtiari to Recent.
Fars Series.
Lower Miocene Limestone.
Oligocene and Eocene.
Cretaceous.
Pre-cretaceous Rocks.

series are seen capping salt at Namakdan. Blocks of serpentine occur in the salt at Jardun.

15. Henjam—Only very scarce occurrences of Paleozoic rocks are seen. The salt is covered by thin representatives of the Mio-Pliocene series. The salt is overlain by Pleistocene terraces which show slight arching due to leaching out of the salt below. The salt is red from included iron oxide. Rhyolite occurs in large masses. Basic rocks also occur.

10. Hormuz—The salt is overlain by only a few patches of Paleozoic rocks, and basic and acid igneous rocks occur.

7. Ginao—There is a continuous unconformity in the Oligocene and Lower Miocene around the margin of the salt mass, caused by its uprise. The salt is overlain by a series of red clays, gypsum, and green tuffs, also conglomerate beds containing pebbles of black dolomite, black chert, and vesicular rhyolitic lava. The salt plug is situated on the eastern pitching-out end of the Kuh-i-Ginao anticline.

6. Kuh-i-Namak (North of Ginao)—The salt-plug occurs at the western pitching end of the Kuh-i-Siah anticline, exposing the Lower Miocene and perhaps the Oligocene. The salt has flowed over the scarps of Miocene limestone and reached the alluvial plain (see description of Anguru, p. 75). Large blocks of rhyolite and serpentine occur, also some black dolomite and purple and blue shale.

5. Kushk Kuh (Tang-i-Bouharegh)—The salt intrusion occurs in a strongly faulted zone. No salt is actually visible, but other rocks of the series occur, black dolomite, red ochreous gypsum and shale, and serpentine.

These rocks appear in several places along the main fault-line between Tang-i-Bouharegh and Neon.

Unconformities and conglomerates with boulders of Hormuz rocks occur in the Lower Miocene, and the Oligocene and Upper Eocene are eroded. At a short distance from the salt intrusion the sequence is normal.

12. Bustanou (*near* Khaneh Surkh)—The surface exposures are mostly basic and acid igneous rocks, the salt only appearing in patches. The plug is surrounded by rocks of Mio-Pliocene series containing pebbles of Hormuz rocks.

9. Anguru (see also p. 75)—Only a few remains of the Paleozoic rocks can be seen. The salt is intrusive through

Cretaceous limestone. The uprise was recent, as no discordances occur throughout the Eocene to Mio-Pliocene series. The salt seems to have arisen subsequent to the formation of the present topography.

13. Puhal—The salt penetrates the Eocene marls. Unconformities and conglomerates with Hormuz rocks occur in the arenaceous group of the Mio-Pliocene series. N.E. of the salt there is a hill 100 ft. high and half a mile long of dark-blue limestone which cannot be younger than Cretaceous. It occupies an anomalous position in relation to the Mio-Pliocene beds.

14. Khamir—The salt is mostly obscured by alluvium. It is intrusive through Rudistid limestone. Large masses of rhyolite occur at Lashtagan and at the sulphur mines, where it has been attacked and decomposed by sulphurous gases.

36. Hamairan—A considerable thickness of rocks of the Hormuz series is exposed (see p. 78). They are intrusive through the Mio-Pliocene series.

37. Al Buza—Similar to Hamairan (see also p. 78). Cambrian trilobites were found here in sandy dolomitic shale.

38. Bostaneh—Similar to Hamairan. Cambrian trilobites were found in greenish shales.

39. Ras Yarid—Similar to Hamairan.

41. Chah-i-Musallam—Only seen from a distance, but it can be seen to contain a thick series of greenish sediments, similar to those at Hamairan.

40. Champeh—Here the cover of the salt includes considerable thicknesses of purple and green saliferous shales with some breccias. Diorites and propylitized basic rocks are also present. Débris from the plug is found in the Eocene globigerina marls, in the Lower Fars, and in the higher parts of the Mio-Pliocene series.

42. Deh Nau (Two miles S. of the village)—This salt-plug had ceased to rise before the Mio-Pliocene rocks were deposited, as they transgress on to the salt without any upturning. Some blocks of the black dolomite group occur in the salt.

43. Mehran—Here, within an amphitheatre of Middle Miocene rocks, lie the remains of an old salt-plug from which

the salt has been removed by erosion. A deep red stain which reaches half-way up the surrounding cliffs indicates its former height; all that remains is a confused jumble of purple and green shales and sandstones in the bottom of the amphitheatre and on the plain outside.

44. EAST OF BASTAK—Here a small plug with salt and purplish sandy shales penetrates Cretaceous limestones.

46. KUH-I-KARMUSTEH; 47. N.E. OF BASTAK; 48. FARIAB; 49. JEBEL TURANJEH; 50. GURZEH—These five salt-plugs lie on a straight line 60 miles in length, running in a direction N. 40° E., and crossing the general trend of the Kainozoic folds obliquely at an angle of 60°. They are very young plugs; the one at Gurzeh (50) is rather more eroded than the others, and is, therefore, probably somewhat older.

Purple and greenish saliferous sandy beds have been observed in 47, 48, and 50, and basic igneous rocks in 49 and 50.

52. KUH WAR—Here a small plug, now deeply eroded, had arisen in the plain at the side of a great anticline; in rising, it brought up with it rocks of the Lower Fars, which have caused an obstruction in the synclinal valley; above the dam the valley has been filled up with alluvium which almost entirely covers the great boulder-fans at the mouths of the gorges in the neighbouring mountains. The rocks of the salt-plug include dark dolomites.

The other recorded plugs in this area, which were not visited by us, are as follows:—

1, 2, 3. TARUM group.
4. TANG-I-ZAGH.
8. TEHRU.
11. LARAK.

17-35. Islands in the Persian Gulf and plugs on the Arabian coast.

45. TUDIRAN.
51. ANVEH.

It may be pointed out that the salt-plugs so far mentioned occupy a zone about 120 miles in width, running roughly N.E. to S.W.

For some distance to the N.W. of this zone no salt-plugs

are known, but in Dashti they reappear, though in smaller numbers. Those examined by us are the following:—

53. Kuh-i-Namak (Dashti) (see also p. 75)—The salt is intrusive through Cretaceous limestone. The uprising of the salt appears to have taken place since the formation of the present topography. The plain at the foot of the mountain is scattered with boulders of dolomitic limestone and dark-red sandstone. From these were obtained a small Cambrian fauna of trilobites and brachiopods. Mr. W. B. R. King has kindly made a preliminary examination of the material; the trilobites are of Middle or Upper Cambrian types, and the brachiopods include a species of *Billingsella*.

54. Kuh-i-Khormuj—On the southern end of the Kuh-i-Khormuj a large area formed by Hormuz rocks occurs. We had no time for close examination.

55. Ahram (Kuh-i-Qaleh-i-Dukhtar)—The Hormuz rocks are in contact with Lower Fars gypsum and have intruded along faults. A conglomerate occurs containing pebbles of dark dolomitic limestone and gypsum.

56. Kamarij—Hormuz salt occurs here in a Lower Fars anticline, but is easily distinguished from a Fars salt by the rocks of the Hormuz series which accompany it, black dolomite and gypsum, etc.

The "dyke" and "metamorphic rocks" mentioned by Mr. R. S. Mackilligin in the vicinity of Ardekan (59, 60, 61) probably belong to the Hormuz series. Mr. Wyllie has also observed similar rocks at Qaleh-i-Gachi, 20 miles E. of Shiraz (58); and near Irij (57) Messrs. Jennings and Gray found trilobites of Middle or Upper Cambrian type in dark dolomite, accompanied by a curious dolomitic shale breccia, like one found by us at Namakdan and elsewhere. The Cambrian rocks are surrounded by Eocene limestones.

63. Do Pulan—Here, at Pul-i-Malik, occurs a series of red and blue shales and massive gypsum, with blocks of black fetid dolomite, with dioritic rocks. One mile above Do Pulan the above sedimentary series is found again, and also a gray dolomitic rock with impressions of salt crystals. No salt is known at either place, but a great mountain of salt is reported to occur at a place 20 miles S.E. of Do Pulan.

Concerning salt occurrences, there has always been con-

siderable controversy, and it is very interesting to note that, in different parts of the world, again and again the same old theories of the origin of the salt are advanced and the right interpretation is only slowly established. This is due to the fact that the salt in its behaviour shows a similarity to the behaviour of igneous rocks.

The salt flows and is squeezed upwards in the form of bosses, or even occupies fault-lines, after the nature of dykes. Further, the scientific results obtained in one country are, unfortunately, often not taken into account in another, and it takes a long time for these results to become generally known.

The facts which must be borne in mind are these :—

1. Rock-salt is capable of flowing like ice. It may be pressed upwards along lines of weakness and form accumulations.

The salt domes of Persia give, perhaps, the most perfect exposures and clearest evidence of this behaviour of the salt. We shall describe two of the most spectacular examples of the flowing of salt, and show how even great salt glaciers may be formed.

Kuh-i-Anguru salt-plug (9) has burst through the highest crest of a long anticline (see Pl. III). Erosion has exposed Cretaceous rocks in the core of this fold, and massive Eocene limestones form an elliptical amphitheatre. The salt appears to have been squeezed out of a central vent in the Cretaceous limestone, and when a great mass of salt had accumulated it began to flow downhill, like an ice glacier. It has almost completely overridden and enveloped the Eocene limestone scarp on the southern flank of the fold, with the exception of two peaks which still protrude through the salt mass. The sketch shows clearly how the flow of the salt was diverted by topographical obstacles and how it finally reached the alluvial plain.

Kuh-i-Namak, in Dashti, S.E. of Bushire (53), affords another example of the rock-salt flowing (Pl. IV, fig. 2). Here also the salt is intrusive through Cretaceous limestone and forms a great mass rising 4000 ft. above the plain. It is situated in a great fault-trough, which crosses the anticline at the crest maximum. As in the case of Anguru, the salt

has flowed down the narrow gorges in the limestone scarp, in this case on both flanks of the anticline, and at the N.W. side of the fault-trough it has completely enveloped the scarp.

2. In some cases an accumulation of salt may take place and yet not reach the surface, retaining a cover of overlying sediments. Under certain circumstances, if the movement of salt has ceased, ground water may leach out the salt to a certain level, forming an even surface, the so-called "Salzspiegel" of German authors. The cover of the salt being unsupported will then collapse and break in, forming a chaotic jumble of rocks above the salt-plug.

In other cases, the salt may reach the surface, and if it is leached out by surface water the rocks in its surroundings will sink and tend to close together. In other cases the leaching-out and erosion may result in the characteristic negative topographic form, the "Salztrichter" of Posepny.

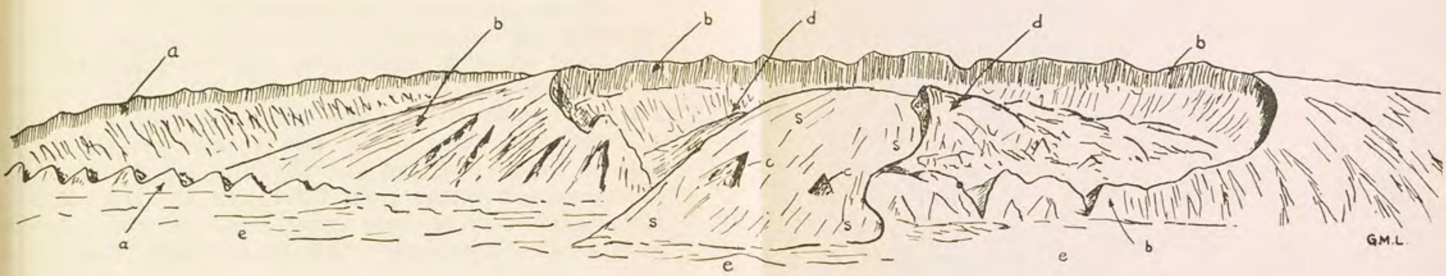
The topsy-turvy jumble of rocks resting on the salt, resulting from these various processes, usually offers a very puzzling problem to the geologist, and often makes it quite impossible to establish any stratigraphical sequence in the original cover-rocks.

3. The movements of the salt and its migration from its original position of deposition towards points of weakness are slow and steady processes, though not necessarily continuous. The uprise is governed by local conditions and therefore may take place at different periods in different localities. Many of the Persian Gulf salt-plugs afford clear evidence of the age of the movement of the salt by the development of conglomerates of various ages in their vicinity.

At Champeh (40), for example, the rocks of the salt-plug have been exposed to erosion in Eocene, Lower Miocene, Pliocene, and recent times.

The salt-plugs are generally more or less oval in horizontal section, owing to the fact that this form demands the minimum force to burst through the covering rocks, which may be already slightly arched.

In some cases the salt and rocks of the salt series are intrusive in faulted zones. The salt may have subsequently been dissolved out, leaving only the gypsiferous marls and



- Field Sketch of Kuh-i-Anguru Salt Dome. -

a - Scarp of Miocene Limestone.
b - Scarp of Oligocene and Eocene Limestone.
c - Peaks of b protruding through Salt.
d - Hippuritic Limestone.
e - Alluvial Plain.
s - Salt mass.

other rocks of the salt series as evidence. Such is the case in Kushk Kuh (5), where Messrs. Fowle and Long have mapped such intrusive rocks (see Pl. V).

If these facts are appreciated, many conflicting observations and interpretations made by workers in salt structures can be understood. For example, the intrusive salt series in Kushk Kuh, mentioned above, has been erroneously regarded as normally interbedded with the Eocene rocks.

The cover of old sedimentary rocks overlying the Hormuz salt has a varying thickness. The most constant rocks are a carbonaceous, strongly fetid black dolomite and dark dolomite shales. The cover of the salt may have undergone erosion to a varying extent, which would account for the varying thickness of these rocks now accompanying the salt. On the other hand, where the salt has been pushed up to a considerable height it has left behind most of its accompanying rocks, and in some domes, such as Kuh-i-Namak (in Dashti) and Kuh-i-Anguru, only fragments of the original cover can be found.

The other extreme is at Al Buza (37) and Hamairan (36), where a considerable thickness of cover rocks may be examined, but the actual outcrop of salt is very limited.

These old rocks at Al Buza are strongly folded and disturbed, as is only natural from their position. A short visit was insufficient to establish the normal sequence of these rocks, to do which would require detailed mapping. The following, however, we could determine :—

At the base lie pink and violet coloured sandstones several hundred feet in thickness. Below these sandstones some gypsum appears at the base of an isolated hill. In some places greenish shales are associated with this sandstone group, the purple sandstones of Pilgrim. Platey sandstones with ripple marks and "salt pseudomorphs" also occur. The name "pseudomorphs" is not, however, correct, as they occur on the surface of sandy shales and may be analogous to the calcite sandstone crystals of Fontainebleau or Wienerwald, the salt having been later leached out. In some cases hollow casts occur. Above this series follow sandy, dark-coloured dolomitic limestones and shales which contain trilobites and casts of annelids.

The trilobites have not yet been determined, and, as far as we have studied them, they could not as yet be identified with known forms. In the case of most of them, the shape of the head-shield, the development of the glabella, of the neck segment, of the occipital ring, cheeks, and pre-glabellar area, the small pygidium, and the fine granulation of the head-shield put the remains close to *Ptychoparia*. An interesting feature is the presence of a well-developed spine on all of the segments. The whole character of the trilobites points to the Middle or Upper Cambrian. This view was fully confirmed by Professor Marr and Mr. W. B. R. King, who have kindly looked at our material.

In several places a white sandstone overlies the pink sandstone group. The platey shales containing trilobites are overlain by dark, fetid dolomites, often containing black cherts.

The difficulty in determining the natural sequence of these rocks has already been mentioned. On account of the movement of the salt, and partly owing to leaching out of the salt from below, the original cover-rocks have collapsed, and a jumble of rocks has been formed. The attitude of the rocks in places suggests imbricate structure, which would explain why in different localities quite different members of the above-mentioned series are found overlying the salt.

Messrs. F. D. S. Richardson and H. K. Long saw the following section at Hamairan :—

5. Brown shaly limestone and marls .	*ca.* 200 ft.
4. Thin bedded green micaceous sandstones, limestones, and marls with ripple marks	*ca.* 600 ,,
3. Purple and green marls, sandstones, and sandy shales, very saliferous, with gypsum along the bedding planes	200-250 ,,
2. Dirty gypsum with bright-red marl and sandstone	3 ,,
1. Purple and green coloured salt .	20 ,, (exposed).

FIG. 1.—PENEPLANED SURFACE OF LOWER FARS, MISHUN AREA, S. PERSIA
In the background a typical major anticline, exposing deep horizons of Cretaceous. On the right in the foreground a synclinal outlier of Middle Fars. (View looking north-east.)

FIG. 2.—SALT-PLUG, KUH-I-NAMAK, DASHTI
CCCC, Cretaceous limestones partly enveloped by salt-glaciers

In Qishm Island, in the Jardun oasis (16), the following rocks overlie the salt :—

4. Anhydrite	*ca.* 2	ft.
3. Dark-coloured calcareous dolomitic shales	*ca.* 4	,,
2. Quartzite	2	,,
1. Dark dolomitic shales	25-30	,,

Dr. R. K. Richardson records the following sequence in his report on Qishm Island :—

"The base of the group is a thin, compact, bedded gypsum associated with crystalline anhydrite. Then follow calcareous sandstones, which are succeeded by dolomitic limestones forming over 80 per cent. of the total thickness of the group."

In other salt-plugs igneous rocks of intermediate, acid, and basic types were observed, and, in certain places, tuffs and agglomerates. A petrological study of our specimens has not yet been possible, but the most important features of their field relations should be mentioned here.

At Al Buza a considerable thickness of conglomerate overlies the Cambrian rocks. The conglomerates are formed of boulders of pink-coloured sandstones and, with the exception of one thin bed containing pebbles of very decomposed basic rocks, they do not contain a single pebble of the igneous rocks occurring in the surroundings. These conglomerates are penetrated by acid and intermediate igneous rocks, rhyolites (or quartz porphyry according to continental nomenclature) and diorites.

It seems, therefore, that after the deposition of the Paleozoic rocks there was a period of erosion when the above-mentioned conglomerates were formed, followed later by a period of intensive vulcanicity. The age of the conglomerate is not known and, as may be deduced from the above, only this much can be said—that the salt is overlain by a series which contains rocks of Middle or Upper Cambrian age, but which may contain some younger Paleozoic rocks too.

In some plugs the amount of igneous rocks present is considerable, as, for example, in Hormuz Island. They form sills and dykes penetrating the dark shales. Endogene and exogene contact-metamorphism can be seen. Some of the sills seem to have a crescentic shape conforming with the

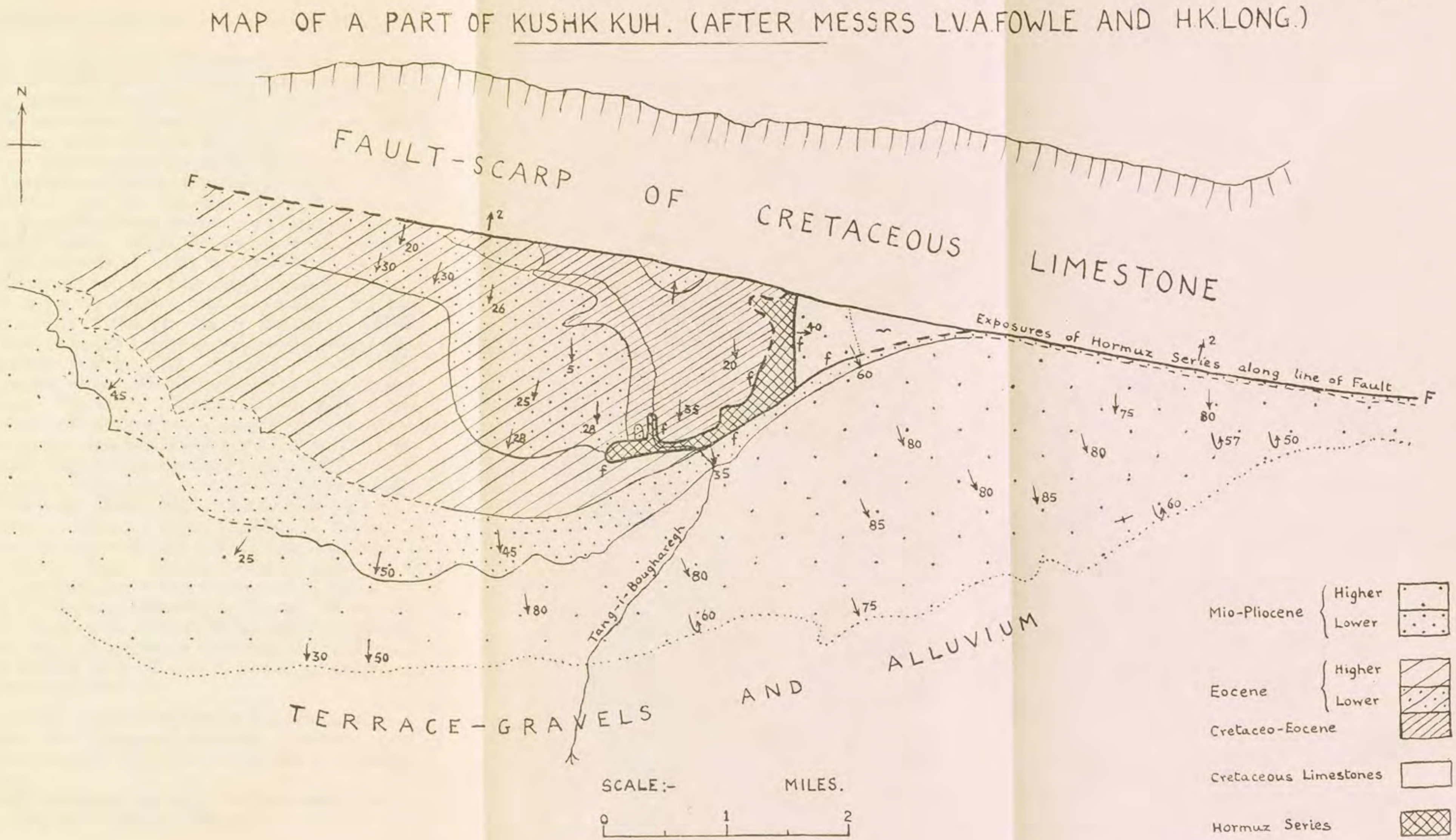
circular shape of the plug. The igneous intrusions in this island would provide an interesting study, but we had not time to make a more detailed examination. Hormuz volcanic agglomerates have been mentioned from here, but we did not see them in the part of the island visited. On the other hand, E. of the village, a rhyolitic intrusion occurs, the scree of which has been re-cemented, giving the appearance of an agglomerate. Tuffs and breccias have been found in other places, for example at Ginao.

In many places the salt is overlain by a series of conglomerates containing a great variety of rocks, gypsum beds, and red gypsiferous marls, the whole containing a varying amount of iron ore. These rocks are the Pusht Tumba group of Mr. Busk. At Henjam (15), it overlies a planed surface of strongly folded salt; at Qishm it is steeply dipping or vertically inclined around the periphery of the salt mass. The age of this group may be completely different in different plugs, but in all cases it has a similar origin. It represents remains of the leaching out of the salt and the washing together of different Hormuz rocks in places where, by leaching out of the salt, depressions have been formed in which various detrital rocks collected, and in some cases lagoons of saline water may have formed and gypsum been deposited. The salt often contains a certain amount of hæmatite which became concentrated in these deposits.

In both Henjam and Hormuz different levels can be seen which have been formed in the salt during the deposition of the Mio-Pliocene series. Each sea-level has a corresponding ground-water level, and by the solution of the salt a "Salzspiegel" will be formed. The residue from the leaching out and the débris caused by erosion will form a conglomerate.

In some salt-plugs, the uprising of which has been more recent, this conglomerate group is lacking; in others the absence of igneous rocks among them suggests that they are of a rather old age.

On Henjam Island we made some interesting observations. In an exposure near the iron-oxide mine a rhyolite boss seems to have penetrated the conglomerate group and to have tilted up the Mio-Pliocene beds around its border. Careful examination, however, failed to prove any caustic or


MAP OF A PART OF KUSHK KUH. (AFTER MESSRS L.V.A.FOWLE AND H.K.LONG.)
N
FAULT-SCARP OF CRETACEOUS LIMESTONE
Exposures of Hormuz Series along line of Fault
Tang-i-Bougharegh
TERRACE-GRAVELS AND ALLUVIUM
SCALE:- MILES.
0 1 2
Mio-Pliocene Higher Lower
Eocene Higher Lower
Cretaceo-Eocene
Cretaceous Limestones
Hormuz Series

pneumatolytic contact with these beds. The explanation is as follows :—

During the formation of a "Salzspiegel," due to solution of the salt, the softer beds sank down, whereas the solid igneous rocks remained like pillars. There are similar occurrences on Hormuz Island, where Pleistocene beds dip away from such igneous knobs at angles up to 60°.

We have not seen any instance of the igneous rocks penetrating the conglomerate group overlying the salt.

A description of the Hormuz series of the Persian Gulf would be incomplete without reference to the problems of the Salt range of India. Much has been written about the age of the salt deposits of India, but it is still unsettled. The "Saline series" of the Salt range consists of rock-salt, gypsum, red marl, dolomite, and trap rocks. The predominating member of the series is the red marl, which is a gypseous marl of bright scarlet to dull purple colour consisting of gypsum and red clay. According to Sir E. H. Pascoe, it is absent westward from Kalabagh, or is represented by grayish clay. The salt is said to be interstratified in the upper part of the red marl and is of a pinkish colour. Potash deposits also occur. Interbedded with the red marl and the salt, but usually higher than the latter, extensive beds and masses of gypsum containing scattered crystals of iron pyrites are described. Brittle flags of dolomite are associated with the gypsum. From the upper boundary of the Saline series intermediate trap with tuffs and ashes are mentioned.

The "Purple Sandstone" overlies the Saline series. It is a soft purple sandstone, sometimes ripple marked, and about 200 to 450 ft. in thickness, according to Wynne. Westward, in the Kharor range, it is overlain by bituminous gypsum, dolomite, and clays. This purple sandstone is the Khewra group, and is overlain by the Kusak (Khussak) group, which has been divided as follows :—

5. Black compact clay slates with mica, containing *Hœferia nœtlingi* Redl. (renamed *Redlichia*, Cossman), *Lingulella wanniecki* Redl., and *Hyolithes* cf. *princeps* Billings.
4. Red sandy micaceous beds with *Neobolus warthi* Noetl., and *Lakhmina linguloides* Waagen.

3. Upper Annelid sandstone. Hard cream-coloured glauconitic sandstones alternating with soft grayish-black beds containing *Ptychoparia warthi* Noetl., *Hyolithes wynnei* Waagen, and *Orthis warthi* Waagen.
2. Blackish-red sandstones with *Hyolithes wynnei* Waagen, and fragments of trilobites.
1. Lower Annelid sandstones.

The sequence of these fossils is uncertain, owing to some confusion about the zones to which Waagen attributed them. Noetling, for instance, thinks that *Ptychoparia warthi* came from Zone 2, and not from Zone 3. The whole group is 20 to 100 ft. thick. Its age is also not settled. Some authors consider it to be of Lower Cambrian age, while others think it belongs to the *Paradoxides* zone.

The Kusak group, also called the Neobolus beds, is overlain by the Jutana or " Magnesian Sandstone " series, which is actually formed of a somewhat sandy dolomite. This series is 150 to 200 ft. thick and contains a mollusc which, according to Sir Thomas Holland, resembles the *Stenotheca* of the American Lower Cambrian. Closely connected with the Jutana group is the Bhaganwala series, which forms the top of the Cambrian deposits. It is 400 to 500 ft. thick, and consists of thin-bedded, flaggy sandstones containing so-called " salt pseudomorphs." These sandstones pass upwards into intensely red argillaceous beds.

The Cambrian deposits are overlain by the boulder bed, a glacial deposit, which is followed by the *Conularia* beds containing a fauna most probably Uralian.

The age of the boulder bed is uncertain. It is most probably a Carboniferous ice-age deposit (thought in earlier times to be Permian). On the other hand, Sir Thomas Holland considers that the basal conglomerate of the Infra-Trias of Hazara, which passes into purple shales and sandstones, is almost certainly identical with the Chitral Devonian. The Hazara conglomerates again have been correlated with the boulder bed of the Salt range, and the purple shales and sandstones with the speckled sandstone of the Salt range which overlies the *Conularia* zone.

These correlations are very confusing, but for our purpose

the salient points are that a saline series is overlain by Cambrian deposits which show lagoon conditions in their upper part, if the sequence is normal. Then comes a great gap and a boulder bed; an ice-age deposit follows. The saline series shows the typical feature of the plastic gypsiferous and saline sediments; Wynne's description of the contact between the saline series and purple sandstone is typical. There is no doubt that the salt has penetrated the purple sandstone, the only uncertainty being whether the Cambrian is overthrust or not.

Some authors consider that the salt is of Kainozoic, probably Eocene age, and that the Cambrian has been thrust over it. Among those who expressed this view are Koken, Noetling, Sir Thomas Holland, Sir H. Hayden, Zuber, Sir E. H. Pascoe, and E. Parsons.[1]

In a recent paper R. v. V. Anderson [2] refers the Saline stage to the Eocene; he states that leaves of dicotyledons were found in well-bedded and laminated calcareous shales in the upper part of the Saline stage in the Khewra valley; he also mentions the presence of calcareous and siliceous shales closely resembling the organic shales of the Nummulitic, and carbonaceous and other shales of Kainozoic lithologic character. Wynne,[3] however, states that N.E. of Khewra, near the road to Kusak, the rocks are greatly dislocated, several fragmentary outliers of Nummulitic limestone and even a small portion of the Eocene coaly shales occurring detached, and probably none of these being *in situ*. On page 158 he mentions the possibility of a general landslip of the beds overlying the salt in the Khewra valley. Anderson's evidence must, therefore, be treated with reserve.[4] It is significant that the Kainozoic along the top of the Salt range contains no possible equivalent of the Saline Stage.

[1] E. Parsons, "The Structure and Stratigraphy of the North West Indian Oilfields," *Journ. of Inst. Pet. Tec.* (1926).

[2] R. v. V. Anderson, "The Tertiary Stratigraphy and Orogeny of the Northern Punjab," *Bull. Geol. Soc. Amer.*, Vol. XXXVIII, p. 672.

[3] A. B. Wynne, "Geology of the Salt Range," *Mem. Geol. Surv. India*, Vol. XIV (1878), p. 157.

[4] See also C. S. Fox, *Rec. Geol. Surv. India*, Vol. LXI, Pt. II (1928).

Wynne has shown that the salt of Kohat in the Punjab is probably of Eocene age. It is only covered by Eocene deposits, whereas the salt of the Salt range has a thick Paleozoic cover.

The salt-plugs of the Persian Gulf are overlain by purple sandstones, sandstones containing " salt pseudomorphs," and sandy dolomites and shales containing Cambrian trilobites. The salt is often iron-stained. One notable difference, however, is that the Persian salt series has been penetrated by various igneous rocks.

The sequence given above, showing the purple sandstone immediately overlying the Hormuz salt, corresponds with the Salt range succession, but does not agree with the sequence given by Pilgrim in his latest memoir.

The Hormuz salt and the Cambrian deposits overlying it break through deposits of Middle Cretaceous age. The latter are definitely *in situ*, and there is no question of their being overthrust, so the salt must be older than Middle Cretaceous, and we shall see from the following that it must be Paleozoic at least.[1] The Hormuz rocks have a very considerable lateral extent, ranging from the surroundings of Bandar Abbas to Kamarij, near Kazerun, in the N., and to Niriz and Do Pulan just in front of the Napped Zone. The great difference in age of the uprise of the salt in different plugs has already been dealt with, but nowhere do we find evidence of the Hormuz rocks coming to the surface earlier than Eocene. Some of the plugs are intrusive into Mio-Pliocene rocks ; others appear from below folded Cretaceous rocks of Aptian or younger age. The Hormuz rocks appear at the surface in the zone of the Foreland (Jebel Sanam) and in the zone of autochthonous folding of the geosynclinal deposits. These deposits range from Valanginian to Pliocene, and attain a considerable thickness. The western shore of this geosyncline was along the Arabian tableland which has from olden times played the rôle of a " Foreland."

This zone of folding belongs to the Mesoids, to the Asiatic continuation of the Dinarids. The salt of the Hormuz series

[1] See M. Stuart, *The Geology of Oil, Oil-Shale, and Coal* (1926), p. 86.

is overlain by Paleozoic rocks, and both are penetrated by igneous rocks, which, however, do not penetrate the Middle Cretaceous. Of this upper limit to its age there is no doubt. Owing to erosion and to the movements of the salt, only scanty relics of the whole volcanic apparatus remain.

We know now that the Cambrian occurs in the Napped Zone and also in the Median Mass (see pp. 136-7).

MESOZOIC

In the zone of folding and shearing, few Triassic or Jurassic sediments have yet been recognized.[1] Stahl shows on his map, in the *Handbuch der Regionalen Geologie*, a large zone of Jurassic rocks in the neighbourhood of Abadeh, but in the text he says they are *perhaps* Jurassic. The deposits in question are limestones, more or less bituminous, containing *Orbitolina* sp. From these beds we collected fossils, some of which Dr. Douglas has kindly examined. They are *Caprinella* aff. *triangularis* (Abbasabad, S.E. of Deh Bid) and *Hypsaster* cf. *douvillei* Cott. and Gauth. (Tang-i-Kamin, N. of Sivand). They are Cretaceous, but the rest of the collected material must be examined before exact correlation can be established.

Our knowledge of the Cretaceous of the S.W. Iranian geosyncline is not satisfactory, partly due to the fact that in many places, from the Cenomanian upwards, a Globigerina facies is developed, which only contains small foraminifera. Moreover, the limestones are themselves often unfossiliferous. The ranges of such forms as *Omphalocyclus*, *Loftusia*, *Ornithaster*, etc., are not yet worked out, especially for the southern territories; and the collected material, which contains new forms, has not yet been determined. Our knowledge may be summarized as follows:—

In the Oman range Messrs. Lees and Washington Gray found the Musandam limestone, 5000 ft. in thickness; it contains a Neocomian fauna at the top, and overlies fossiliferous sandstones and shales of Upper Triassic age. The greater part of the limestone should therefore belong to the Jurassic.

[1] Jurassic and possibly Trias have now been found in the Zimkan valley, 35 miles N.E. of Paitaq.

In the S.W. Iranian geosyncline, the oldest known Mesozoic rocks proved by fossils are Valanginian.[1] Thirty-two miles N.W. of Sulaimani, near Qamsho, Dr. Andrau found *Duvalia dilatata*, Blainville, and also several Upper Valanginian ammonites. In the S. around the Persian Gulf and the Gulf of Oman, older rocks may be exposed. In Dashti, in the Kuh-i-Kartang, and again near Barak and Asalu, a thick series of deposits is exposed beneath the Globigerina marls. In Kuh-i-Kartang the top 550 ft. consist of rubbly and marly limestones, of which the upper part contains large *Radiolitidæ*, and a small distinctive species of *Biradiolites*, while the lower part has yielded *Hemiaster* cf. *fourneli* Desor,[2] assigned to the Turonian. Below these follow 300 ft. of well-bedded limestones, containing at the top an *Acanthoceras* [3] fauna, which is Cenomanian. Then follow 450 ft. of marls with limestones containing, about the middle, the "Cenomanian" forms,[1] *Diplopodia variolare* Cott., *Orthopsis granularis* Cott., *Codiopsis* cf. *doma* Desm., *Pedinopsis* aff. *desori* (Coquand), *Holectypus* aff. *excisus* Cott., and *Exogyra flabellata* (Goldf.). Then follow 800 ft. of limestones, near the middle of which (1150 ft. below the *Acanthoceras* horizon) occurs a *Hinnites* very similar to a Neocomian form, *Hinnites renevieri* Pict. and Camp., described by Dr. Lees from Oman. Below these rocks occur 650 ft. of gypsum and porous dolomites, and then 200 ft. of limestones and dolomites.

Near Asalu the *Radiolitid* fauna of Kuh-i-Kartang occurs 150 ft. below the top of the Cretaceous limestones. Five hundred feet below the top are marly beds with the "Cenomanian" [4] forms, *Orthopsis granularis* Cott., *Codiopsis* cf. *doma* Desm., *Holectypus* aff. *excisus* Cott., *Anorthopygus orbicularis* Cott., *Diplopodia* near *pseudo-ornatum* Cott., *Salenia* cf. *plena* Fourtau, *Epiaster* near *crassissimus* d'Orb, and *Exogyra flabellata* (Goldf.), and, in addition to these, fragments of *Knemiceras* and a single specimen of *Lyelliceras*, the last-named identified by Dr. Spath and assigned to the Middle Albian. Below this horizon follow 630 ft. of limestones, then 500 ft. of limestones and dolomites, then 700 ft. of gypsum and dolomites, and then 750 ft. of pink limestones.

[1] See footnote, p. 85.
[2] Identified by Dr. Douglas.
[3] Identified by Dr. Spath.
[4] Identified by Dr. Douglas.

It is worthy of note that in Kuh-i-Kartang the top of the gypsum-dolomite series is 2100 ft. below the top of the Cretaceous limestones, and at Asalu about 1500 ft., although the distance below the *Codiopsis* marls is about the same in both cases. Further investigation is necessary to determine whether the gypsum-dolomite group in the two places is really of the same age, and what is the age of the underlying limestones. It must be pointed out that the *Codiopsis* fauna and the *Knemiceras-Epiaster* fauna (which is found in several other places) are associated with a distinctive shallow-water facies of reddish and greenish marls with glauconite, so that they must be treated strictly as facies-faunas for the present. The association of " Albian " ammonites with " Cenomanian " echinoids may, in view of the nature of the deposits, be due to a condensed sequence; but it is also possible that the echinoids in question have a longer time-range than is supposed.

Returning to the neighbourhood of Sulaimani, in the Asmir Dagh behind Sulaimani, de Böckh, A. Trowbridge, and the late J. R. Bourchier found *Puzosia*, and other fossils of Albian type, amongst them *Oxytropidoceras* sp.[1] They occur in sandy calcareous marls and limestones.

E. of Erbil, in the Safin Dagh, de Böckh and P. Viennot found *Orbitolina concava* Lam. in well-bedded marine limestones, which should therefore be Cenomanian.

In Pusht-i-Kuh, in the Kuh-i-Valamtar, which is a part of the S.W. flank of the Kabir Kuh, de Morgan collected fossils from dark-coloured limestones; they were identified by Douvillé as *Parahoplites milletianus* d'Orb, and *Douvilleiceras cornuelianum* d'Orb. They are regarded as Aptian. Elsewhere in the Kabir Kuh, de Morgan found bluish limestones which contain in their lower part *Turrilites bergeri* A. Brogn., and *Puzosia denisoniana* Stol., and in the upper part *Acanthoceras laticlavium* Sharpe, *A. gentoni* Defr., *A. rotomagense* Defr., *A. cunningtoni* Sharpe, etc. The lower part is Upper Albian (Vraconnian), which is regarded by some authors as basal Cenomanian; the higher part is Cenomanian.

In the Kuh-i-Bingistan, S.E. of Marmatain, R. L. C. Bleeck

[1] Identified by Dr. Spath.

found *Cheloniceras* sp. in the deepest exposed beds of the Cretaceous limestones. A loose specimen of *Pseudophacoceras*, of the group of *Schloenbachia roissyana* d'Orb, was also found. These fossils indicate that Aptian and probably Albian are present. Both identifications are by Dr. Spath.

The lowest exposed part of the Cretaceous consists mostly of dark-coloured or deep blue limestones. It is important that as yet, direct superposition of Eocretaceous on older rocks has nowhere been observed in the Folded Zone.[1] Perhaps, however, some evidence might be found in the neighbourhood of Sulaimani. Where pre-Cretaceous rocks do come to the surface in the form of Hormuz inliers, the contact is always abnormal and due to the intrusive behaviour of the Hormuz salt.

The Cenomanian, Turonian, and Senonian (including Maastrichtian and Danian) show a great diversity of development —limestones, Rudistæ limestones, Globigerina marls and a Flysch facies are to be found. In the Globigerina marl and the Flysch facies, fossils are scarce. The Globigerina marls, especially when developed in a petroliferous facies, yield nothing but foraminifera. Marcasite nodules are common, but no molluscs or gastropods are present. They are the deposits of a sea-bottom where the oxygen was insufficient to support benthoic organisms.

We have already mentioned the Cenomanian limestones of the Safin Dagh. Above these follow Rudistæ limestones, then 400 ft. of platy limestones, and finally a Flysch and sandy marl facies about 2800 ft. thick. The sandy Flysch beds contain greenish and reddish chert detritus, apparently derived from the Radiolarite Nappe; the marls are dark and carbonaceous. Near the top of these beds occurs a limestone containing *Orbitolites complanatus* Lam. var. *pharaonum* Schwager, as determined by M. Viennot.

In the surroundings of Sulaimani, Flysch occurs above Middle Cretaceous. The rocks are much folded, and further study is necessary to disentangle the detailed stratigraphy. At Aqra, bituminous calcareous shales, with a fauna yet to be determined, are overlain by Rudistæ limestones, 900 ft.

[1] See postscript, no. 1, p. 214.

thick, containing *Toucasia*. Then come calcareous marls with *Loftusia*, which, however, also occurs below the *Toucasia* limestones. Then follow calcareous Globigerina marls, and above them about 170 ft. of reddish beds. The anticline is overturned and faulted.

Near Dohuk the lowest rocks exposed are limestones with Globigerinæ and other foraminifera. Then follow Globigerina marls with interbedded limestones in the lower part; red and green sandy marls and red sandstones; and then a series about 300 ft. thick of gypsum and red marls. This group is overlain by Alveolina limestones.

But there are also red beds above the Eocene limestones, as for instance in the Bazian Pass near Sulaimani or in the Safin Dagh. In these Eocene beds conglomerates occur, indicating proximity of a shoreline, the consequence of Laramide movements.

In the Kalhur and Pusht-i-Kuh country Globigerina marls develop above the Cenomanian (see Stratigraphical Columns, Pl. VI). In the Imam Hassan anticline (S.E. of Qasr-i-Shirin) the Cenomanian limestone is not exposed, but it is to be found in other ranges of the country. In the Siah Kuh anticline, Dr. Smellie collected *Metacanthoplites*, cf. *rotomagense* Defr. The sequence, as exposed in the Imam Hassan anticline, is :—

1250 ft.	Green and purple Globigerina marls.
900-1000 ,,	Cream-coloured calcareous marls.
1200 ,,	Blue and black Globigerina marls with *Lopha dichotoma* Bayle.
,, ,,	*L. zeilleri* Bayle, *L. pectinata* Lam.
,, ,,	*L. morgani* Douv., *Gryphæa vesicularis* Lam.
c. 100 ,,	exp. Hard limestones.

From the surroundings of Dalpari and Deh Luran, from Imam Hassan, Shakar Ab, Kabir Kuh, Danah Khushk, and other places, Senonian fossils have been collected. Professor J. W. Gregory and Miss E. D. Currie made the following determinations :—

Lopha dichotoma Bayle.
,, *zeilleri* Bayle.

Lopha pectinata (Lam.).
,, *morgani* Douv.
,, *ungulata* Schloth.
Exogyra matheroni d'Orb.
Pseudoheligmus morgani Douv.
Spondylus subserratus Douv.
Plicatula hirsuta Coq.
Neithea tricostata Bayle.
Trigonia orientalis Forbes.
Gryphaea vesicularis (Lam.).
Terebratula brossardi Thom. et Pér.
,, *toucasi* d'Orb.

Besides this there are several echinoids identical with those described by Cotteau and Gauthier, and the following new forms :—

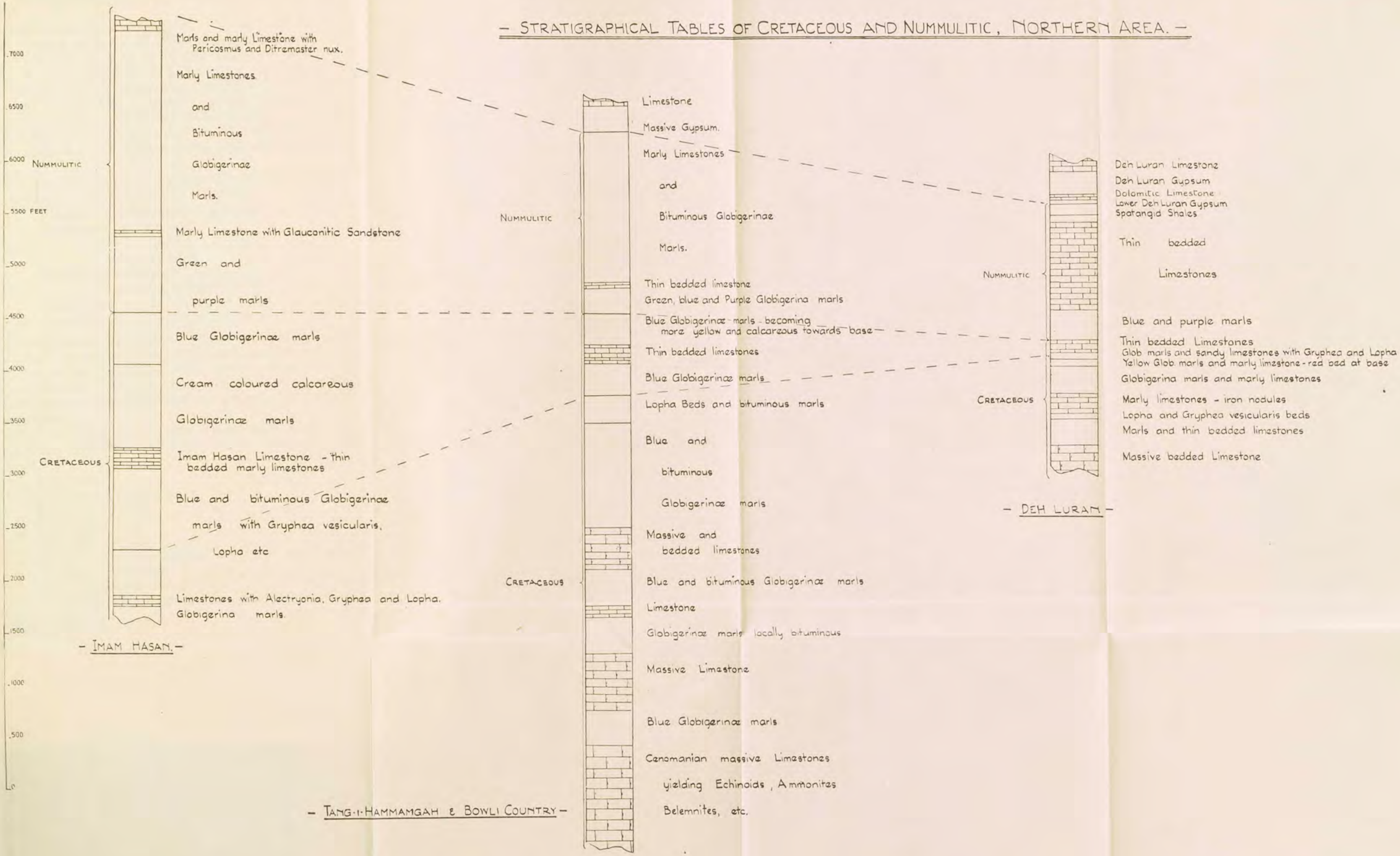
Codiopsis smellii Currie and Gregory.
Epiaster smellii Currie.

The fauna is of Senonian age.

The fossils occur in calcareous marls and marly limestones interbedded with Globigerina marls. Above and below the fossiliferous marls are considerable thicknesses of Globigerina rocks. The fossiliferous marls and marly limestones have been called the Lopha beds on account of the frequent occurrence of that form.

De Morgan collected many fossils from Upper Cretaceous in Luristan, which were determined by H. Douvillé, Cotteau, and Gauthier. Amongst these fossils occur *Hemipneustes persicus* Cott. and Gauth., *Bostrychoceras polyplocum* Ronsen, *Sphenodiscus acutidorsatus* Noetl., which were considered by Douvillé to represent the Campanian. *Omphalocyclus macropora* Lam. is taken to indicate the presence of Maastrichtian, while *Ornithaster douvilléi* Cott. and Gauth., and many gastropods showing Kainozoic affinities have been put into the Danian. These rocks are said to contain *Loftusia morgani* Douvillé. These correlations are, however, not safe.

The lack of the characteristic fossils of some zones is due to the fact that these divisions are represented either by unfossiliferous limestones or Globigerina marls.


– STRATIGRAPHICAL TABLES OF CRETACEOUS AND NUMMULITIC, NORTHERN AREA. –
7000
6500
6000
5500 FEET
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
NUMMULITIC
CRETACEOUS
Marls and marly Limestone with Pericosmus and Ditremaster nux.
Marly Limestones and Bituminous Globigerinae Marls.
Marly Limestone with Glauconitic Sandstone
Green and purple marls
Blue Globigerinae marls
Cream coloured calcareous Globigerinae marls
Imam Hasan Limestone - thin bedded marly limestones
Blue and bituminous Globigerinae marls with Gryphea vesicularis, Lopha etc
Limestones with Alectryonia, Gryphea and Lopha.
Globigerina marls.
– IMAM HASAN. –
NUMMULITIC
CRETACEOUS
Limestone
Massive Gypsum.
Marly Limestones and Bituminous Globigerinae Marls.
Thin bedded limestone
Green, blue and Purple Globigerina marls
Blue Globigerinae marls becoming more yellow and calcareous towards base
Thin bedded limestones
Blue Globigerinae marls
Lopha Beds and bituminous marls
Blue and bituminous Globigerinae marls
Massive and bedded limestones
Blue and bituminous Globigerinae marls
Limestone
Globigerinae marls locally bituminous
Massive Limestone
Blue Globigerinae marls
Cenomanian massive Limestones yielding Echinoids, Ammonites Belemnites, etc.
– TANG-I-HAMMAMGAH & BOWLI COUNTRY –
NUMMULITIC
CRETACEOUS
Deh Luran Limestone
Deh Luran Gypsum
Dolomitic Limestone
Lower Deh Luran Gypsum
Spatangid Shales
Thin bedded Limestones
Blue and purple marls
Thin bedded Limestones
Glob marls and sandy limestones with Gryphea and Lopha
Yellow Glob marls and marly limestone - red bed at base
Globigerina marls and marly limestones
Marly limestones - iron nodules
Lopha and Gryphea vesicularis beds
Marls and thin bedded limestones
Massive bedded Limestone
– DEH LURAN –

Near Khurramabad, Messrs. R. C. Jennings and K. W. Gray report that 2000 ft. of thin bedded limestones and shales are overlain by 1000 ft. of red chert-conglomerates, and that these are followed by a limestone with *Rudistæ*, *Loftusia morgani* and *Omphalocyclus macropora* Lam.[1] This development of the Maastrichtian increases towards the north-west, attaining a thickness of over 6000 ft. at the Sirwan River. The sands are composed entirely of detritus from the zone of green igneous rocks and red and green cherts.

In the Bakhtiari country, de Morgan collected the following fossils between Do Pulan and Shalil (Djelil) :—

Praeradiolites ponsianus d'Archiac.
Radiolites trigeri Coquand.
,, *peroni* Choff.
,, *morgani* Douv.
Biradiolites lumbricalis d'Orb.
,, *persicus* Douv.
Polyptychus morgani Douv.
Loftusia persica Carp. and Brady.

The first five forms would indicate Turonian; *Biradiolites persicus*, *Loftusia persica*, and *Polyptychus morgani* were at first referred to the Santonian; but in the explanation of his plates Douvillé, though referring the *Biradiolites* to the Santonian, classes *Loftusia persica* and *Polyptychus morgani* as Maastrichtian.

In the Kuh-i-Bingistan, in the Tang-i-Abul Faris and Tang-i-Machar, the following sequence was observed by Mr. Bleeck :—[2]

20 ft.	Anhydrite.
240 ,,	Gray limestone and marls.
220 ,,	Yellow limestones.
180 ,,	Gray limestones.
1150 ,,	Globigerina marls.
360 ,,	White to cream shales and calcareous marly limestones (*Ditremaster ?*).
1000 ,,	Limestones with *Radiolites*.
610 ,,	Limestone. Near the top *Hemiaster* sp.

[1] Identifications by Dr. Douglas. [2] *Ibid.*

500 ft. Black and bluish bituminous marls.
650 ,, Limestones, with *Cheloniceras* sp. in the top beds (Aptian).

The anhydrite bed occurs below shales which underlie the Asmari limestones (see p. 103). It is impossible to draw a boundary between the Cretaceous and the Eocene here. S.W. of Niriz Messrs. Jennings and Gray found a Senonian fauna in the basal part of a limestone scarp 2500 ft. in height. The fossils include *Hippurites cornu-vaccinum* (Bronn), *Pyrina orientalis* Cott. and Gauth., and *Pygurostoma morgani* Cott. and Gauth. At the top of the scarp occur Alveolina and Flosculina (identifications by Dr. Douglas).

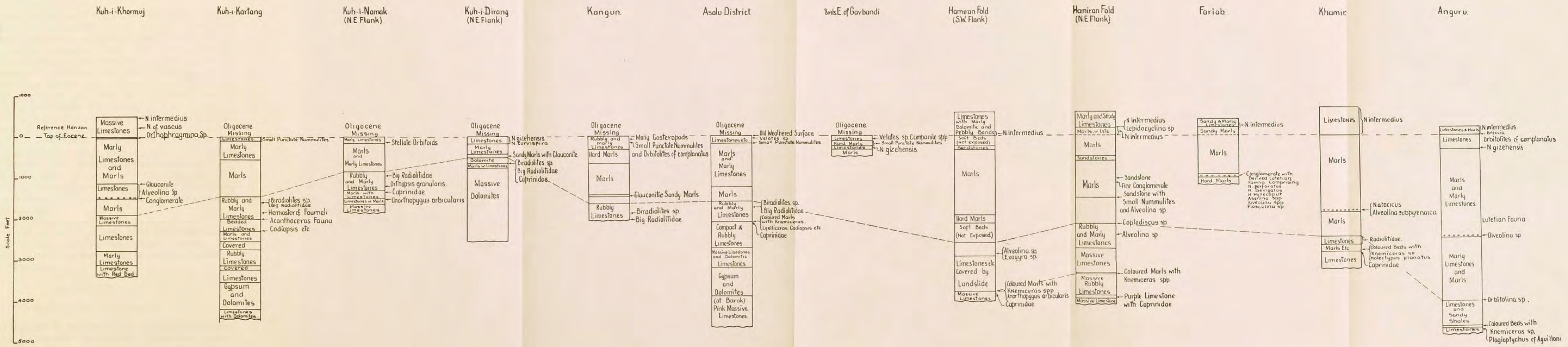
In Dashti at several places the Cretaceous is separated from the Eocene by a conglomerate. Where this conglomerate is not present, it is not possible to say where the Eocene begins.

In Dashti and to the S.E. a very thick limestone series is exposed below Globigerina marls. In the Kuh-i-Gisakan, a few feet above the top of the limestones, Messrs. Russell and Pitt found a Turonian fauna with *Romaniceras*,[1] *Pseudaspidoceras*,[1] *Lopha sollieri* Coq.,[2] *Hemiaster* cf. *fourneli* Desh.,[2] and *Inoceramus cripsianus* Mant.[2] In the Kuh-i-Kartang, Kuh-i-Dirang, Kuh-i-Namak, and its continuation past Kangun and Asalu, *Rudistae* (*Biradiolites*, etc.) are found near the top of the limestone (see Pl. VII). We have mentioned that in the Kuh-i-Kartang an *Acanthoceras* fauna is present. At Hamiran, *Knemiceras*, large *Epiaster*[2] and *Anorthopygus orbicularis* Cott.[3] occur 1200 ft. below the top of the Cretaceous limestones. In the Kuh-i-Anguru, below an Alveolina limestone-conglomerate, the following sequence is to be observed :—

About 1550 ft. marly limestones with chert, greenish thin bedded marly limestones.
Globigerina marls, slightly bituminous.
A limestone pebble-bed with some plant-remains.
650 ft. gray limestone with *Orbitolina* at the top ; green

[1] Identified by Dr. Spath. [2] Identified by Dr. Douglas.
[3] *Ibid.*

STRATIGRAPHIC COLUMNS OF THE CRETACEOUS AND NUMMULITIC OF THE SOUTHERN REGION.



and brown sandy shales with limonite concretions.
Brownish limestones with *Knemiceras* sp. *Caprotina* sp.
At the base bright-coloured marls with thin gypsum beds.
Sulphur springs from this horizon.
Massive gray limestone with *Plagioptychus aguilloni* d'Orb.

Dr. Douglas writes that the last-named fossils seem to agree fairly closely with d'Orbigny's figure. *Plagioptychus aguilloni* would indicate Turonian, and if this is so a higher gypsum horizon is present here.

In the Khamir anticline Globigerina marls follow below the Eocene basal conglomerates, then a *Rudistæ* limestone with *Radiolites*; then green and reddish marly beds, and at their base a sandy limestone with *Holectypus planatus* Rœmer, which according to Dr. Douglas is indistinguishable from specimens in his collection from Peru; *Knemiceras* and large *Epiaster* occur about this horizon; then follows a limestone with *Caprinula* and then the abnormal contact with the salt-plug (see profile, Pl. VIII).

In the Kushk Kuh anticline, below an *Alveolina* limestone, which has a conglomerate at its base containing *Alveolina sub-pyrenaica* Leym., *Flosculina globosa* Leym., and *Orbitolites complanatus*, follow about 1500 ft. of green shales with many conglomerate bands. The contact with the underlying thick limestone was not found. In the areas in the neighbourhood of the Kushk Kuh, the conglomerates in the Upper Cretaceous beds contain pebbles of the Cretaceous limestones exposed in the core of the anticline.

As we said, our knowledge of the Cretaceous is not at all satisfactory, but it is clear that over large areas there is a distinct break between the Cretaceous and Eocene. The only important Cretaceous movement is pre-Maastrichtian and probably Senonian.

KAINOZOIC

Nummulitic or Palæogene

The Eocene deposits of the Folded and Sheared Zone show in six general facies—the Nummulitic limestone, Alveolina limestone, Miliola limestone, Globigerina marl, Flysch, and sandstone facies. The distribution of these facies has not

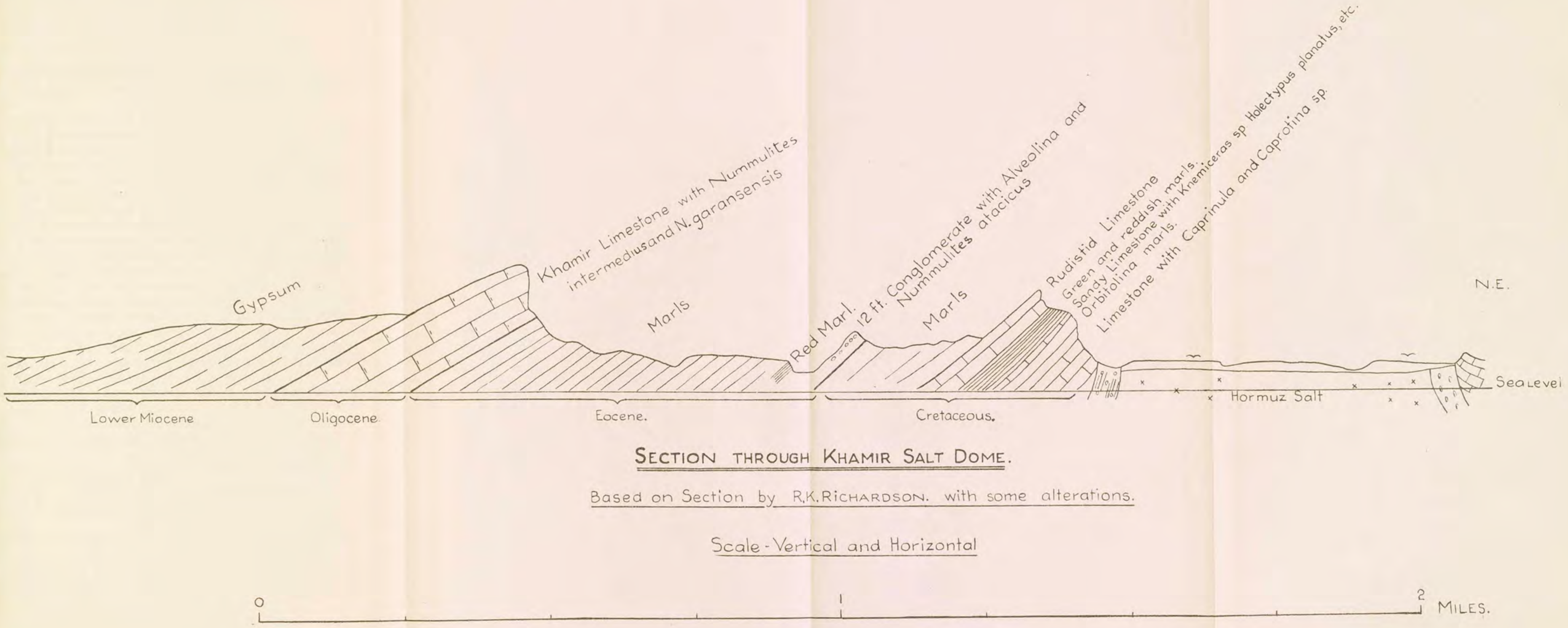
yet been worked out in detail. The development of an unfossiliferous Globigerina facies—unfossiliferous as far as fossils other than the smaller foraminifera are concerned—makes the zoning of the Eocene as difficult as the zoning of the Cretaceous.

As we have seen, in the Foreland the Middle Eocene is known and is formed of limestones. In the Folded Zone W. of the Tigris in the Jebel Atshan, Nummulitic limestone is exposed, containing *N. distans-tchihatcheffi*. These limestones are overlain by a conglomerate, and then follows the Miocene Asmari limestone. Below the Nummulitic limestone, shales seem to occur. Similarly in the S. part of the Qara Chauq Dagh, below limestones containing *Lepidocyclina* cf. *formosa* follow well-bedded limestones, below which Globigerina marls are exposed. In the N. Qara Chauq Dagh, above the well-bedded limestones, occur limestones with *N. intermedius-fichteli*. According to M. Viennot these Nummulites may be called *N. sub-brongniarti* Verb. which is the reticulate Oligocene form of Java and Borneo.

In a zone which is exposed in the anticlines of Dohuk, Aqra, and Safin Dagh and in the Bazian Pass near Sulaimani, at the base and within the Eocene, sands, pebbly beds and even gypsum occur. In the Jebel Makhlub, below limestones (probably of Oligocene age) follow about 130 ft. of bedded limestones, then about 330 ft. of marls, then a series of red and grayish marls with gypsum, then a red sandstone.

In the Bazian Pass, the following section has been observed :—

Rubbly conglomeratic limestone. Limestone (white chert concretions at the top, marly at the base) . . .	*ca.* 350 ft.
Conglomerate	,, 6 ,,
Sandy marls. Conglomerate. Red and yellow marls and conglomeratic sandstone	,, 50 ,,
Limestone	,, 15 ,,
Dolomitic limestone passing into conglomerate. Nummulites . .	,, 18 ,,
Yellow sandy marls	,, 35 ,,



SECTION THROUGH KHAMIR SALT DOME.

Based on Section by R. K. RICHARDSON. with some alterations.

Scale - Vertical and Horizontal

Conglomerate	ca.	6 ft.
Yellow and gray marls and limestones, slightly sandy, with *Flosculina globosa* Leym., *N. subatacicus* Douv., *N. atacicus* Leym., and *Lucina* sp. .		70 ,,

The deepest beds are either basal Lutetian or perhaps the top of the Lower Eocene. Below this series follow Flysch-like beds.

In the Safin Dagh to the E. of Erbil, on the top of Flysch-like rocks a limestone occurs which contains, as we have seen, *Orbitolites complanatus* var. *pharaonum* Schwager. Then follow Globigerina marls; above them red marls and sandstones, and then a chert conglomerate. Above this conglomerate a greenish-gray marl is to be observed, which is overlain by a limestone of probably Oligocene age.

We have discussed the section of Dohuk (see p. 89). The Alveolina limestone contains *A. oblonga* d'Orb and is Lutetian, and below it the gypsiferous beds and the red and green beds are deeper Eocene, and in part probably Cretaceous. It is evident that in these regions Laramian movements are indicated, followed by an Eocene transgression; later sandy and pebbly deposits develop, indicating movements during and at the end of the Eocene, and the Oligocene is again a time of transgression. The pebbly and sandy facies of the Eocene is present in the neighbourhood of Karind on the Kermanshah-Qasr-i-Shirin road (cf. postscript, no. 2, p. 214).

The Globigerina facies, as exposed in the Jebel Atshan, develops to the S.E. in the Imam Hassan anticline. Here the Cretaceous cream-coloured Globigerina marls, 900 to 1000 ft. in thickness, are overlain by the following sequence:—

1200 to 1800 ft. Globigerina marls—at the top the so-called Spatangid shales.
20 to 40 ft. Limestones and glauconitic sandstones.
1250 ft. Green and purple marls.

The green and purple group is very widespread at the base of the Eocene in the Pusht-i-Kuh country, Luristan, the Bakhtiari country and Dashti. In the Khamir anticline, a conglomerate containing *Alveolina* and *N. atacicus* Leym. is

overlain by reddish shales. These red beds, which in many places are not separated from the Cretaceous by a definite break, seem to correspond at least partly to the Lower Eocene, but may even represent the lower part of the Middle Eocene.

In the zones in which the Globigerina facies prevails, fossils are extremely scarce or completely absent, with the exception of small foraminifera. Towards the top, however, there is a zone containing Echinoids such as :—

Schizaster vicinalis Ag. and Des.
S. rimosus Des.
Ditremaster nux Des.
Euspatangus ghiavanensis Gauth.

These forms have been determined by V. Gauthier as Upper Eocene, but such Spatangidæ are as a rule not reliable zone fossils, and there are places where the Spatangid shales are overlain by Lepidocyclina limestones.

In the Kuh-i-Khaiz, E. of Behbehan, big *Lepidocyclinæ* of the type of *L. elephantina* Mun.-Chalm. are found above the Spatangid shales, so that further studies are necessary to decide whether the Spatangid shales may not in places represent the Oligocene.

N.E. of Iman Hassan, in the Pai Taq anticline, the Eocene is developed in the facies of Globigerina marls and limestones on the S.W. flank; on the N.E. flank more limestones develop, and beyond the Pai Taq Pass, Nummulitic limestones are found, with *N. millecaput* Boubée, *N. gizehensis* Forskal, and *Discocyclina* sp. To the S.W. of Imam Hassan, in the Tangao and Paromal anticlines, the Globigerina facies of the Eocene prevails everywhere. A. J. Goodman found here 1500 ft. of Globigerina marls, then thin-bedded limestones which pass downwards into the characteristic green and purple shales. Above the green and purple shales a massive limestone bed occurs, probably corresponding to the limestone and glauconitic sandstone beds of the Imam Hassan anticline.

To the S., at Kulaki Buzurg, the following sequence was observed by W. M. Gray and J. R. Bourchier :—

Marls and limestones (Globigerina facies). About 100 ft. from the top *Pericosmus* sp. occurs	1150 ft.
Green and purple shales . . .	450 ,, (exposed).

In the Dalpari-Deh Luran area, on the S.W. flank of the Siah Kuh, the following sequence is exposed :—

Globigerina marls (towards the top *Pericosmus* cf. *nicaisei* Pomel and *Schizaster rimosus* Desor)—[1]	
Platey limestones with chert . . .	900 ft.
Blue and purple shales	410 ,,

The contact between the Eocene and the younger beds is faulted, and the Globigerina marls (Spatangid shales) form a recumbent fold.

In the Tangao and Paromal anticlines and Kulaki Buzurg, and the Siah Kuh, the Pericosmus shales are overlain by gypsum. In Kuh-i-Asmari only the highest beds of the Eocene are exposed. Here thin-bedded limestones and marls with *Ditremaster nux* Desor,[1] and Globigerina limestones are exposed, which are about 350 ft. thick. Then comes about 250 ft. concealed by scree, then 250 ft. of blue shales with *Schizaster*,[2] then 15 ft. of anhydrite. In the Kuh-i-Bingistan, in the Tang-i-Abul Faris, and Tang-i-Machar sections, the following sequence is exposed above massive Radiolitic limestones :—

6. Anhydrite	20 ft.
5. Gray limestones and marls . . .	240 ,,
4. Yellow limestones	220 ,,
3. Gray limestones	180 ,,
2. Blue and yellow Globigerina marls .	1100 ,,
1. White to cream calcareous shales and marly limestones	360 ,,

In this unfossiliferous series it is at present impossible to tell how much is Cretaceous, how much is Eocene, and how much is Oligocene.

[1] Identifications by Dr. Douglas. [2] *Ibid.*

In the more easterly zones of deposition, sections have been studied in the Bard-i-Qamcheh gorge and the Dasht-i-Gul. In the Bard-i-Qamcheh gorge only the Spatangid shales are exposed. The lower part is formed by 100 ft. of thin bedded limestones containing *Ditremaster nux* Desor, the upper part by 260 ft. of shales with *D. nux* and *D. foveatus* Desor. These beds are overlain by limestones containing *Lepidocyclina* (*Eulepidina*) *dilatata* Michelotti and *L. raulini* Lem. and Douv.[1]

In the Dasht-i-Gul section, the following sequence can be observed :—

7. Shales	250 ft.
6. Globigerina limestones and marls .	1000 ,,
5. Nummulitic limestones with *Assilina exponens* J. de C. Sow, *A. spira* de Roissy, *A. granulosa* d'Archiac, *N. lævigatus* Brug, *Orthophragmina* sp.[2] .	*ca.* 250 ,,
4. Basal conglomerate with *Assilina mammillata* d'Arch, *N. uroniensis* Heim, and *N. perforatus*, A and B, de Montfort	50 ,,
3. More or less bituminous Globigerina marls ; at the top blue, purple and dark-coloured marls and clays containing calcareous sandstones with "hieroglyphs"	1200 ,,
2. Thin-bedded marly limestones with *Globigerina*	1200 ,,
1. Dense limestones (Cretaceous).	

The above series is overlain by limestones with *Lepidocyclina dilatata* Michelotti.

In Dashti and down to the Zindon range, the following faunas have been distinguished, which correspond closely with the N.W. Indian faunas as worked out by Dr. Nuttall :—

3. Large Nummulites of *N. gizehensis* type, occasionally with a very large (apparently new) species of *Assilina* (*e.g.* Kushk Kuh) ; alternatively very small punctate Nummulites.

[1] Identifications by Dr. Douglas. [2] *Ibid.*

2. A rich varied fauna of large punctate *Nummulites*, *Assilina*, *Orthophragmina*, and *Alveolina*.
1. *Alveolina* fauna with radiate *Nummulites* and *Orthophragmina*.

No. 3 would correspond to Nuttall's Higher Middle Khirthar, No. 2 to the Lower Middle Khirthar, and No. 1 to the Laki series which is assigned by Nuttall to the upper part of the Lower Eocene.

A fauna of gastropods (*Velates schmiedelianus* Chem. and large *Campanile*) occurs in many places, but in more than one position in the sequence. From S. Dashti to Beh Deh and in the Bastak region, the gastropod fauna is found above beds containing *N. gizehensis* Forskal. In the Kushk Kuh the gastropods occur between the *Alveolina* fauna and the rich varied foraminiferal fauna, and they have a similar position in the Kuh-i-Ginao. As we shall see, in these areas the Oligocene is partly missing and partly overlies the Eocene unconformably (cf. postscript, no. 3, p. 214).

Oligocene

In the Foreland near Haditha, as we have seen, *N. intermedius-fichteli* occurs in pebbles and as remaniés in the matrix of a breccia underlying the Euphrates limestone. We have mentioned the Oligocene occurrences in the Qara Chauq Dagh. In the neighbourhood of Dohuk and Aqra limestones develop which may be of Oligocene age. In the Safin Dagh and at the Bazian Pass they overlie the red beds of the Eocene, and seem to indicate an Oligocene transgression. Thick limestones are known N.E. of Mosul, which may also be partly of Oligocene age, but all these localities have yet to be studied.

In the Pusht-i-Kuh country, we have no typical Oligocene fossils, and as we have mentioned, at several places the Spatangid shales are overlain by gypsum.

W. of the Euphrates and in the Qara Chauq Dagh, conglomerates occur at the base of the Miocene Asmari limestone, which, from Kerbela up to Ramadi, shows a strong overlap. As the conglomerate below the Asmari contains pebbles of the *N. intermedius-fichteli* limestone and of a

coral limestone the age of the regression indicated by the conglomerate must be younger than the *N. intermedius* limestones, and older than the Burdigalian part of the Asmari. It is only logical to suppose that the anhydrite and dolomitic limestone series which, as we shall see, in many places underlies the Asmari, should correspond to the topmost part of the Oligocene, and to the Aquitanian—taking the latter as the base of the Miocene. This lagoon series overlies Spatangid shales, as mentioned on page 99, and it is therefore very probable that the Spatangid shales of several localities correspond to limestones elsewhere containing *N. intermedius-fichteli*.

Another difficulty is that we do not know what value the *Lepidocyclinæ* may have as zone fossils in this part of the world. In the Kuh-i-Dira limestones for instance, *Nummulites intermedius* is associated with *Lepidocyclina* cf. *schlumbergeri* Lem. and Douv. (Determinations by Dr. Douglas.)

The *Lepidocyclinæ* are large and show affinities with *L. dilatata* Michelotti. The *Lepidocyclinæ* seem often to form a facies of the *N. intermedius* limestones. Further studies will be necessary to clear up this question.

To the S. of the Kuh-i-Dira, in the Kuh-i-Qaleh Dukhtar, the Oligocene is developed in a Nummulitic limestone facies with *N. intermedius-fichteli* and a Nummulite related to *N. vascus* Joly and Leym.

The Oligocene Nummulitic limestone occurs also in Kuh-i-Khormuj, but in S. Dashti and to the S.E. thereof the Oligocene seems to be absent. In the Kuh-i-Dirang, for instance, the gypsum beds of the Miocene directly overlie a limestone with *N. gizehensis* Forskal and its megalospheric form *N. curvispira* Savi and Meneghini. Farther south-eastwards, from Ishkanan to Khamir and Puhal, we find Oligocene limestone up to 600 ft. in thickness. These limestones are often crowded with reticulate nummulites of *intermedius* type, and occasionally contain *Lepidocyclinæ* of moderate size. Eastwards from the Kuh-i-Gavbust, we find the Oligocene Nummulitic limestones separated by sandy shales from a weathered surface of the Eocene limestone. Towards the east the Oligocene becomes thinner, more sandy, and con-

glomeratic, and overlies the Eocene unconformably, as for instance in the Kuh-i-Ginao, Kuh-i-Siah, and Kushk Kuh.

As seen from the above, our knowledge of the Oligócene is rather limited. We have Nummulitic limestones in Iraq, again from Kuh-i-Dira to the Kuh-i-Khormuj, and from Ishkanan to Puhal. They pass down into shales (where exposed), and in these places the Oligocene cannot be exactly divided from the Eocene marls.

Then we have a Lepidocyclina limestone facies, the correlation of which is in many places questionable; we do not know if they are still Oligocene, or whether they may be Miocene. Then we have a marly facies which cannot be distinguished from the Eocene. From Bastak to Kushk Kuh a sandy and conglomeratic facies is developed, and we may mention here that sandy Oligocene Nummulitic limestones also occur near Shiraz. Locally gypsum or anhydrite beds are developed, which may be of Oligocene age.

As we see, in several places, especially in the Pusht-i-Kuh and the Bakhtiari country, the Oligocene rests absolutely conformably on the Eocene. In the neighbourhood of Sulaimani and the Safin Dagh, on the other hand, an Oligocene transgression is to be observed, whereas in parts of Dashti and down to Kushk Kuh, Pyrenean movements are expressed. We have no evidence about the behaviour of the Oligocene in the area between the Kabir Kuh and the nappe zone, or about large areas of the Bakhtiari country, Dashti and Fars. Approaching the napped zone, and even the sheared zone, one might expect to find expression of Pyrenean movements, but this task is left to the further examination of these areas.

THE MIO-PLIOCENE OR NEOGENE

THE ASMARI LIMESTONE AND ITS EQUIVALENTS

At the close of the Oligocene great changes took place in the conditions of deposition. As we have said, W. of the Euphrates the Burdigalian Euphrates limestone is separated by conglomerates from the underlying Oligocene and Eocene. At Haditha, these conglomerates contain *Nummulites intermedius-fichteli.* Similar conglomerates are known in the

Jebel Atshan where they overlie limestones containing *N. tchihatcheffi-distans*; in the Qara Chauq Dagh, where they overlie Oligocene Nummulitic limestones (Pl. IX, fig. 1); and in the neighbourhood of Sulaimani, for instance in the Bazian Pass. On the S.W. flank of Jebel Makhlub the conglomerate occurs between the gypsum beds of the Lower Fars and the underlying limestones, but it is not yet certain whether these limestones represent the Nummulitic or the Lower Miocene. In connection with this regression and erosion period, which is certainly younger than the *N. intermedius-fichteli* beds, over large areas lagoon conditions set in, and anhydrite, shales, and more or less dolomitic limestones were deposited. In Burdigalian times, a transgression took place over these lagoon deposits and conglomerates, and a limestone was deposited. The regression and lagoon conditions included the Aquitanian. The Burdigalian limestone shows a variable thickness. It is the same with the gypsiferous series. In the Imam Hassan anticline a limestone which corresponds partly to the Burdigalian limestone attains a thickness of the order of 400 to 500ft. In the Tang-Ao anticline, in the Ab-i-Gilan section, the thickness of the Burdigalian limestone is about 150 ft., and the gypsiferous series below attains a thickness of 300 ft. At Kulaki Buzurg Messrs. W. M. Gray and Bourchier measured 300 to 400 ft. of lagoon (gypsiferous) deposits, overlain by 200 ft. of limestone. Further S., near Dalpari, marls containing *Ditremaster nux* are followed by a 30 ft. gypsum bed, then 70 ft. of dolomitic limestone, and then a gypsum series which is 250 ft. thick. Interbedded with this gypsum are red and green marls very similar in appearance to Lower Fars deposits, from which, however, they are separated by 250 ft. of Lower Miocene limestone. Towards Deh Luran, the red and green marls disappear, and only thin limestone beds occur in the lagoon series. In Kuh-i-Asmari itself, the following series was observed :—[1]

Lower Miocene (Asmari) limestone .	900 ft.
Blue shales and yellow limestones, with *Brissopsis* cf. *biarritzensis*, Cotteau, and *Echinolampas placenta*, Duncan and Sladen	100 ,,

[1] Identifications by Dr. Douglas.

FIG. 1.—MIOCENE BASAL CONGLOMERATE, QARA CHANG DAGH, 'IRAQ

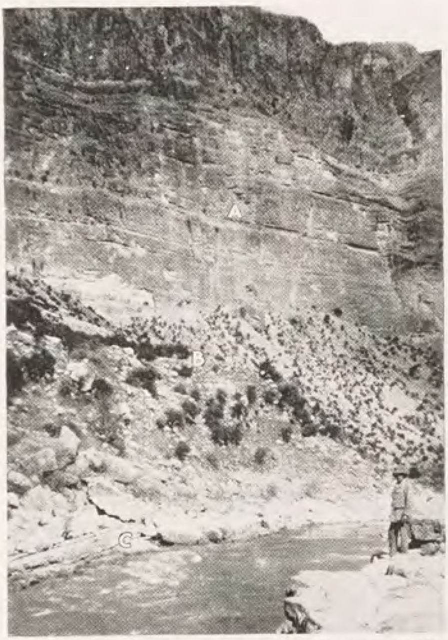


FIG. 2.—SECTION IN BARD-I-QAMCHEH GORGE, S.W. PERSIA
A, Lower Miocene Limestone; B, Eocene Spatangid Shales, covered by scree; C, Eocene Thin-bedded Limestones, with Spatangidæ

Anhydrite	15 ft.
Blue shales with *Schizaster*	250 ,,
Beds obscured by scree	250 ,,
Thin-bedded limestones and marls with *Ditremaster nux* Desor, and Globigerina limestone	350 ,,

In the Kuh-i-Bingistan, Mr. Bleeck observed the following sequence :—[1]

Lower Miocene limestone	900 ft.
At the top, *Ostrea* cf. *latimarginata* Vred., *Æquipecten* aff. *siniensis* Lam.; lower down, *Euspatangus rostratus* d'Archiac and Haime, and *Echinolampas* sp. Blue shales and yellow marls.	
Anhydrite	20 ,,
Gray limestone and marls	240 ,,

In the Bakhtiari country, at the Bard-i-Qamcheh gorge and Dasht-i-Gul, the so-called Spatangid shales of the Eocene are overlain by a limestone, which at its base contains *Lepidocyclina* (*Eulepidina*) cf. *dilatata* Michelotti at Dasht-i-Gul, and *L. dilatata* var. *elephantina* Mun.-Chalm., *L. dilatata* Michelotti, and *L. raulini* Lem. and Douv. at Bard-i-Qamcheh (Pl. IX, fig. 2). Here the anhydrite bed of Kuh-i-Asmari and Kuh-i-Bingistan is not present. In the Mishun area N.E. of Ganawah, in the Kuh-i-Dira, there are 390 ft. of massive crystalline limestones, which contain gypsum nodules and lenses. In these limestones *Kuphus arenarius* (Linn) occurs. Below them follow about 130 ft. of massive limestones, and then, in the Tang-i-Imam Hassan Ghazi, 15 ft. of limestones with *Nummulites intermedius-fichteli* are exposed. It is most probable that the anhydrite beds in Kuh-i-Asmari and Kuh-i-Bingistan represent the break between the Nummulitic and the Miocene. In the more southerly areas, apparently more stable conditions set in after the deposition of this anhydrite bed, whereas to the N. the lagoon conditions were more persistent. E.S.E. of

[1] Identifications by Dr. Douglas.

Bushire, in the Kuh-i-Khormuj, the following section can be observed :—

Massive gypsum	220 ft.
Interbedded gypsum and gray marls. At the top, red marl bands	200 ,,
Marls and limestones	330 ,,
Massive gypsum	1200 ,,
Well-bedded limestones with *Kuphus arenarius* and *Asmaria*. Red and green marls	370 ,,
Limestones with *Nummulites intermedius-fichteli* and *N.* cf. *vascus* . . .	420 ,,

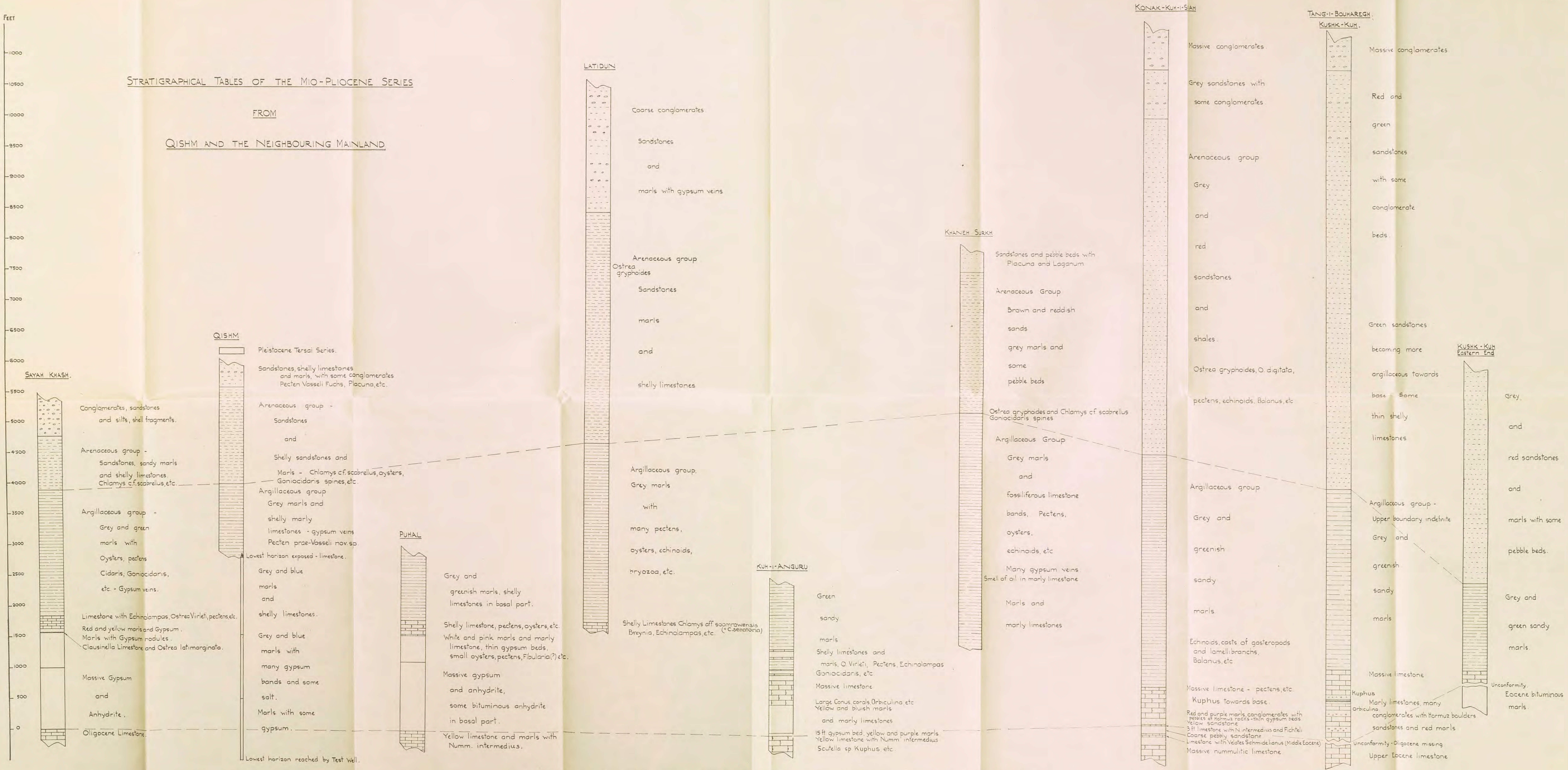
In the Kuh-i-Dirang, the gypsiferous series overlies limestones containing *Nummulites gizehensis* Forskal. Here the Oligocene and the Asmari seem to be missing. To the E. of Kuh-i-Dirang the Lower Miocene limestone is perhaps represented by thin breccias and limestones with *Kuphus* and *Orbiculina* which occur just above the top of the Eocene limestones (see Pl. X). Further down the Persian Gulf, N.E. of Charak, *N. intermedius-fichteli* limestone is overlain by about 2000 ft. of massive gypsum and anhydrite with some limestone groups, and at Khamir it can be well observed how the Oligocene Khamir limestone is overlain corformably by the massive gypsum and anhydrite, with some intercalated gray and greenish marls and limestone beds. The gypsiferous series thins farther eastwards, and on the S. flank of the Kuh-i-Anguru, near the salt-plug, the gypsum is only 10 to 15 ft. thick. At the E. end of the Kuh-i-Ginao, W. of the sulphur-springs, 50 to 60 ft. of gypsum was observed.

The above-mentioned Lower Miocene limestone has been called " Asmari Limestone." Dr. Douglas examined during 1923, the fossils of the Asmari limestone of Deh Luran, Dasht-i-Gul, Masjid-i-Sulaiman,[1] Kuh-i-Asmari, Bard-i-Qamcheh, and Kuh-i-Dira, and from his work it gradually became clear that the Asmari limestone proper is of early Miocene and perhaps partly Oligocene age.[2] Dr. R. K. Richardson

[1] Referred to in previous literature as Maidan-i-Naftun.

[2] *Flabellipecten burdigalensis* Lam. occurs in some places. We think that only the limestone above the Aquitanian break indicated over large areas by gypsum or anhydrite beds should be called Asmari limestone.

Stratigraphical Tables of the Mio-Pliocene Series from Qishm and the Neighbouring Mainland



Stratigraphical columns showing stratigraphical variations in the Mio-Pliocene in Dashti and to the South-East

correlated, on the basis of Dr. Douglas's determinations, the limestones of the above localities, and included the Khamir limestone in the Asmari. The Khamir limestone, however, with its *N. intermedius-fichteli*, is older than the Asmari proper. The correlation of the Lepidocyclina beds of Dasht-i-Gul and Bard-i-Qamcheh remains a difficulty, and we have already pointed out that the correlation of the so-called Spatangid shales demands further study.

From the above it is clear that after the deposition of the beds containing *N. intermedius-fichteli*, a regression of the sea took place, and lagoon conditions set in over large areas. These lagoon conditions are strongly developed in Pusht-i-Kuh, less accentuated in Kuh-i-Asmari and Kuh-i-Bingistan, and are again strongly developed in the neighbourhood of Charak. In certain places, such as Dasht-i-Gul, Bard-i-Qamcheh, and the Mishun area, marine conditions continued during the period following the deposition of the *N. intermedius-fichteli* beds ; whereas, in those areas where the lagoon and shoal conditions develop, a transgression took place, which resulted in the deposition of the Lower Miocene limestone (Euphrates limestone, Kalhur limestone, Deh Luran limestone, Asmari limestone). This limestone thins out towards the Kuh-i-Dirang. In the areas N. of the Kuh-i-Dirang, and into Iraq the limestones are followed by the lagoon deposits of the Lower Fars. In Dashtistan and Fars the base of the Lower Miocene is generally formed by gypsiferous and red beds, in thickness up to 2000 ft. and more. The marine beds overlying the gypsiferous beds are partly limestones, partly silts, and often resemble Middle Fars (cf. postscript, no. 4, p. 214).

The Fars and Bakhtiari Series—(See Pl. X, XI)

At the close of the deposition of the Asmari limestone, lagoon conditions became more widespread, and a thick series of gypsum, anhydrite, salt, marls, silts and limestones was deposited, which has been named " Lower Fars." The term " Fars " was first used by Dr. Pilgrim, who divided the " Gypseous Group " of Loftus into a " Fars Series " and " Bakhtiari beds." The former he subdivided into a basal

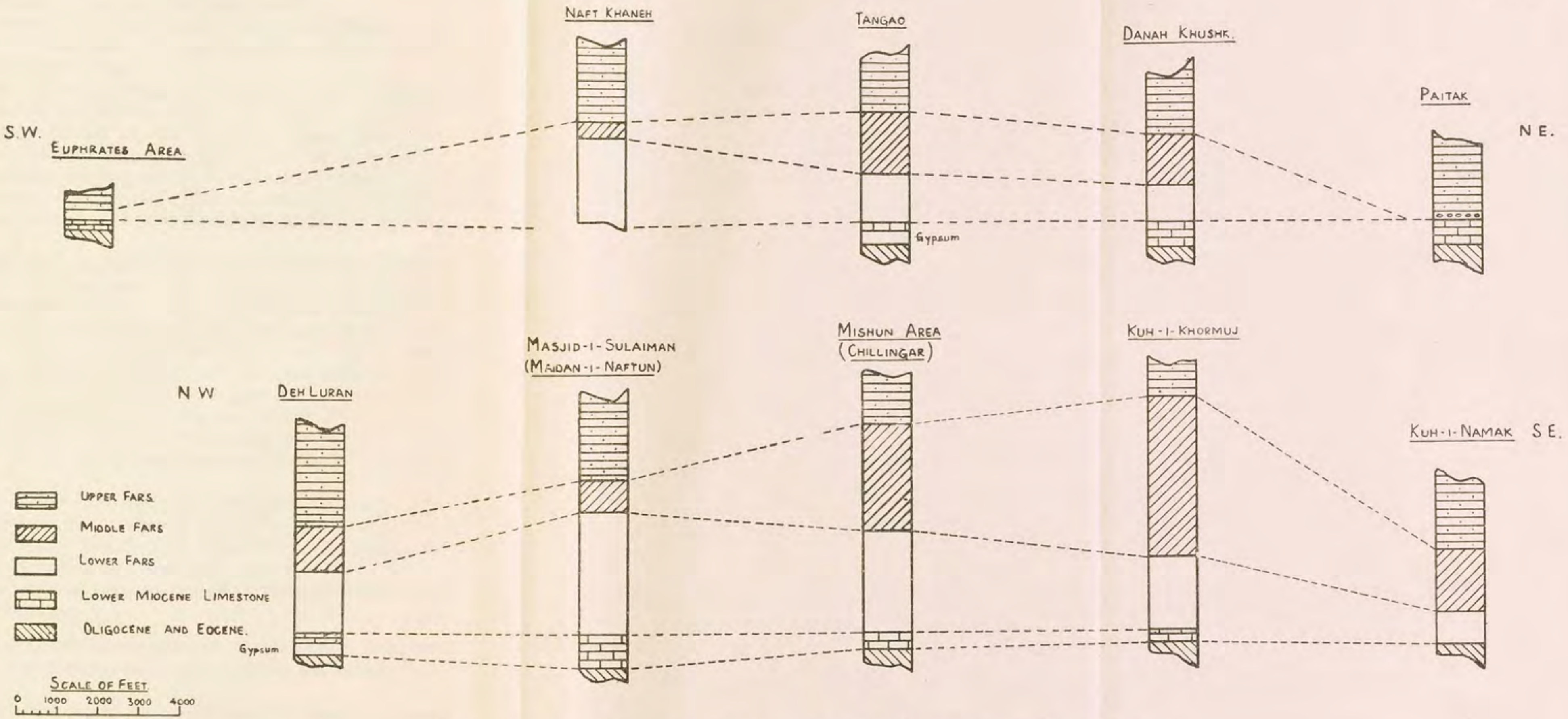
gypseous group, *Ostrea virleti* beds, and *Pecten vasseli* beds. The divisions made by Dr. Pilgrim are not well defined. We have seen that in the neighbourhood of Charak the basal gypsum beds overlie the Oligocene limestones concordantly, and they are *not* time-equivalents of what is called "Lower Fars" in the country N.W. of the Mund River. Pilgrim gives for the *Pecten vasseli* beds a thickness of about 1000 ft., and puts the series at the top of the Mio-Pliocene deposits. He says that in Qishm and Henjam they overlie the Hormuz series.

In Qishm the deepest exposed bed which we found was in the Salakh dome. It is the limestone which gives the oil-shows. Here occurs a *Pecten* similar to *P. vasseli* Fuchs, but it differs from it by the width of the five principal interspaces and the early development of the riblets which divide them. It is closely related to *P. vasseli* and may be called *P. præ-vasseli*. This *Pecten* occurs in Henjam also in the deepest exposed beds; its highest occurrence was in Qishm about 800 ft. above the lowest bed exposed.

Then comes a series which contains *Chlamys* (*Æquipecten*) cf. *scabrellus* Lam. var.

Only the top beds, about 400 ft. thick, which occur below the so-called Tersai series, contain the true *P. vasseli* Fuchs. Moreover, *P. vasseli* is not constant throughout the area and has only been found close to the Persian Gulf. In the Khaneh Surkh structure it is very scarce. At Sayah Khash, Puhal, Kuh-i-Ginao, Kuh-i-Siah, and Kushk Kuh we did not find it at all. Seven miles N. of Lingeh, however, it is extremely abundant, and it occurs rather sparingly at the S.E. end of Kuh-i-Dirang in Dashti. In each case it is found in the highest beds of the Mio-Pliocene series.

Pascoe (*Mem. Geol. Surv. India*, Vol. XLVIII, 1922) divided the Mio-Pliocene series of Iraq into two parts, the gypseous Hamrin stage below, and the fluviatile Kurd series above. He tentatively correlated the Hamrin stage with the Lower Fars and Middle Fars of Persia, and the Kurd series with the Upper Fars and Bakhtiari. This correlation is correct in a general way, with the reservation that, as we shall show, the boundary between the Middle and Upper Fars is a facies-change rather than a time-horizon. In the Kifri region he



Stratigraphical Sections showing Lateral Variation of Fars Deposits.

G.M.L.

made several subdivisions in the Kurd series, but, owing to lateral variations, they are only valid locally.

In the neighbourhood of Masjid-i-Sulaiman,[1] Messrs. S. L. James, G. W. Halse, and others divided the Fars into Lower, Middle, and Upper groups.

The Lower Fars represents a gypsiferous and saliferous series, and is the best defined of the Fars groups ; the Middle Fars is largely normal marine, and the Upper Fars fresh-water. But the commencement and end of the Lower Fars lagoon conditions are not contemporaneous in different parts of the country. We have seen that the Lower Miocene limestone is represented by a Lower Fars facies in the surroundings of Charak.

Mr. Fowle and his colleagues have shown that between Gurgir and Ab-i-Lashkar beds which show Middle Fars marine development in the former place pass laterally into gypsum in a S.E. direction, while the basal part of the Upper Fars passes into a marine Middle Fars type. In the same way time-correlation of Middle Fars between different areas is very difficult. Mr. Nason Jones and his colleagues have proved by mapping that fossiliferous Middle Fars beds to N.W. of Marmatain pass north-westwards into rocks of Upper Fars type, which are unfossiliferous or generally very poor in fossils.

The term Lower Fars signifies a stratigraphical stage with certain variations in the ages of its Upper and Lower boundaries. The terms Middle and Upper Fars and Bakhtiari, however, apply rather to facies development.

The Lower Fars at outcrop can be divided in certain areas into three stages :—

III, or Upper Stage—Whitish in colour and composed of massive gypsum beds, gray marls, and marly limestones.

II. Middle or Red Stage—Formed by massive gypsum and anhydrite beds, red gypsiferous marls and some limestones and sandstones.

I. Basal Stage—Whitish in colour and composed of massive gypsum beds, thin bedded marly limestones and yellowish marls and clays and mudstones.

[1] Referred to in previous literature as Maidan-i-Naftun.

In the Mishun Area the thickness of these stages was determined by Mr. Mackilligin as follows:—Upper stage, 160 ft.; Middle stage, 600 ft.; Lower stage, 2000 ft. In boreholes it is different. Here at depth anhydrite and rock-salt are encountered. The groups are:—

> *III, or Upper Group*—Gray and blue marls with anhydrite.
>
> *II, or Middle Group*—Red marls with anhydrite, shelly limestones, sandstone beds and lenses, and some salt.
>
> *I, or Basal Group*—Stage D: Gray marls with strong salt beds, occasional limestone traces. Stage C: Oily gray shales and muds, with anhydrite which often shows radial structure. Shelly limestone lenses. Stage B: Massive salt beds with subordinate shales and anhydrite. Stage A: Beds of radial anhydrite with gray and oily shales. At the base radial anhydrite and shales, the anhydrite often with limestones.

At Naft Khaneh Mr. A. J. Goodman has determined the following sequence in the Lower and Middle Fars:—

Middle Fars	Includes limestones with Rotalidæ, and also a gypsum bed . . .	400 ft.
Lower Fars	4. Anhydrite group . .	1000 ,,
	3. Salt group .	250 to 350 ,,
	2. Salty marl group, passing over into anhydrite .	170 ,,
	1. Transition beds, limestones, anhydrite, oily shales etc. . . .	275 ,,

Group 1 contains three well-marked limestones; the lowest is oolitic, with many small gastropods and some ostracods; the middle limestone is not oolitic, with ostracods, some gastropods, and Milioline foraminifera; the highest is a marly limestone with *Pecten* and Rotaline foraminifera.

It is characteristic that, although many salt springs are known, the only recorded outcrop of salt of this age is at Ambal on the Karun River, where there occurs a salt-plug

FIG. I.—CONTORTED LOWER FARS, ZURAH RIVER

FIG. 2.—THE FRONT OF THE CRETACEOUS NAPPE, LOOKING E.S.E., NEAR KERMANSHAH

he low ground to the right of the mountains is occupied by the Radiolarite Nappe

which is apparently formed by Lower Fars salt. Over most of the areas the salt has been completely leached out to a certain depth.

In structures where a considerable overburden is preserved in the synclines, while the cover of the Lower Fars has been largely or totally removed in the crestal part of the anticlines, the Lower Fars shows very complicated contortions.

The specific gravity of the rocks is—Lower Fars, 2·23; Middle Fars, 2·18; Upper Fars and Bakhtiari, 2·36.

The Bakhtiari conglomerates are often well cemented and have an even higher specific gravity.

The complicated contortions of the Lower Fars (Pl. XII, fig. 1) are not merely a case of disharmonic folding. There are some anticlines in which no sufficient overburden is present, and in them the Lower Fars conforms to the structure of the Asmari limestone and of the overlying beds. The amount of salt present is another factor on which the degree of contortion of the Lower Fars depends. The transformation of anhydrite into gypsum and the leaching out of salt are additional factors. There seems to be, further, a connection between the thickness of the Lower Fars and the degree of contortion. The maximum amount of contortion coincides in Persia with areas in which the Lower Fars attained an original thickness of 3000 ft. or more.

The Lower Fars is often squeezed out in places where the overlying beds have been eroded away, and it may flow out and cover an eroded surface of Middle and Upper Fars and Bakhtiari (see Pl. XIII). The squeezing out sets in when erosion has removed the cover, so that much of the movement is entirely due to pressing out by overburden.

At the same time we have to admit that epeirogenetic movements, causing the slow folding of major anticlines and synclines, may also play a part in the squeezing out of the Lower Fars; but when overflow-sheets are formed, the squeezing out of the Lower Fars has no connection with orogenetic movements and might be classified amongst the synepeirogenetic movements. These overflow sheets, which in certain cases reach a width of more than two miles, ride over folded and eroded Bakhtiari, and are therefore younger than the Wallachian movements.

We know cases in which the Lower Fars shows no sign of disharmonic folding in zones of strong folding, where the folds are close to one another.

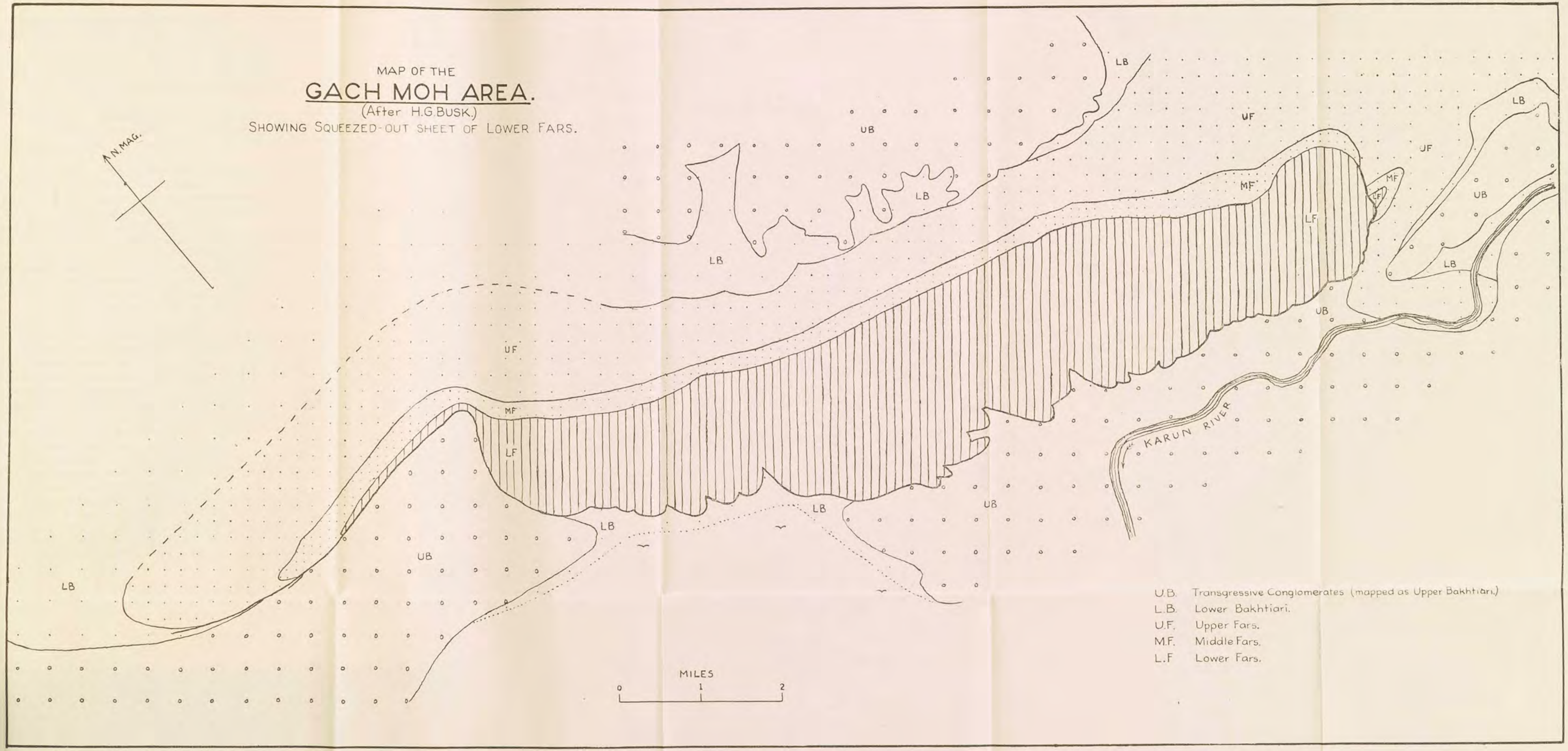
It is interesting to mention that the Asmari limestone, when exposed in the cores of anticlines, is often surrounded by a belt of strongly folded Lower Fars, where the Upper Fars and Bakhtiari are or have been thick too. The development of this belt shows no relationship whatever to the degree of folding of the Asmari limestone. One can find strongly folded regions where no contortion of the Lower Fars occurs, and gently folded regions where strong contortion of the Lower Fars can be observed.

The Lower Fars shows a very variable development. In places the Lower Fars thins out rapidly towards the N.E. and it is in some localities separated by a breccia or conglomerate from the underlying Lower Miocene limestone. For example, on the Paitaq Pass, on the Baghdad-Kermanshah road, the *Nummulitic* limestone is overlain by a conglomerate followed by beds of Upper Fars type, and no gypsum is present. In the Dizful area Mr. J. Nason Jones observed only 150 ft. of Lower Fars in the Kuh-i-Ayir, and in the Diz River sections near Liwas and Sisar, only 50 ft. At the latter place there is a basal shore-conglomerate 9 inches in thickness. Basal breccias or conglomerates are also known from the N.W. end of the Kuh-i-Khaiz near Behbehan, and also from several places farther to the N.E., as at Chinar Radah, 15 miles west of Shiraz. In other places, however, the Lower Fars extends for a considerable distance into the mountains, and there is generally perfect conformity between the Lower Fars and the Lower Miocene limestone.

In Masjid-i-Sulaiman it can be proved that the higher stages overlap towards certain parts of the anticline.

In the Gach-i-Turush or Sulabadar structure near Mishun, the thickness decreases towards the crest of the anticline. Some of the anticlines already existed as gentle folds in Lower Fars times.

We cannot deal here in detail with the Lower Fars, but we wish to point out that in Iraq and Naft Khaneh, limestones, which are often oolitic or foraminiferal, have a considerable extension in the Lower Fars. The thickness also varies


MAP OF THE
GACH MOH AREA.
(After H.G.BUSK.)
SHOWING SQUEEZED-OUT SHEET OF LOWER FARS.
N. MAG.
LB
UB
UF
MF
LF
KARUN RIVER
MILES
0 1 2
U.B. Transgressive Conglomerates (mapped as Upper Bakhtiari.)
L.B. Lower Bakhtiari.
U.F. Upper Fars.
M.F. Middle Fars.
L.F Lower Fars.

considerably. It is of the order of 1800 ft. in the surroundings of Mosul, 2200 ft. in Naft Khaneh, 3000 to 3300 ft. at least in the surroundings of Masjid-i-Sulaiman. In the surroundings of Bushire in the Kuh-i-Khormuj, the thickness is 1950 ft., in the Kuh-i-Dirang 650 ft., and even less near Asalu, where the group consists almost entirely of marls, with little or no bedded gypsum.

The Lower Fars contains very few species. The most common are *Ostrea latimarginata* Vredenburg, and *Venus* (*Clausinella*) sp., and an occasional *Ostrea* of *gingensis* type.

The Middle Fars—The Lower Fars is followed by a series which shows a marked marine influence. The thickness of this series is very variable. In the surroundings of Mishun it attains a thickness of 2800 ft., but towards the N.W. it becomes very thin, only a few hundred feet.

It is formed by bluish and grayish marls and limestones. In the surroundings of Mishun occur limestones up to 400 ft. in thickness; among them is a coral limestone. In this region the Middle Fars contains a rich fauna which shows a Vindobonian character, but the fauna still awaits detailed study. Here the principal fossils, as determined by Dr. Douglas, are as follows:—

Ostrea virleti Desh., *Ostrea digitata* Eich. var. *rohlfsi* Fuchs, *Pecten* (*Chlamys*) *multistriatus* Poli, *Pecten soomrowensis* Sow., *Venus* (*Chione*) *cancellata* Sow., *Venus nonscripta* Sow., *Spondylus crassicosta* Lam., *Lithophagus lithophagus* Linn., *Echinolampas* cf. *jacquemonti* D'Arch. and Haime, and large Cardium-like forms. *Ostrea gingensis* Schl. appears near the Middle-Upper Fars boundary. This well-marked fauna extends far to the S.E. and also as far to the N.W. as White Oil Springs and Khalafabad.

In the surroundings of Masjid-i-Sulaiman and to the west thereof, the thickness of the Middle Fars becomes much less, and the fauna is much poorer in species.

The commonest forms are: *Pecten* (*Chlamys*) *multistriatus* Poli, *Venus nonscripta* Sow., *Tapes* cf. *protolirata* Noetl., small species of *Arca, Dosinia, Melongena,* etc., together with *Ostrea gingensis* Schl. At Gurgir, 16 miles S.E. of Masjid-i-Sulaiman, was found a small *Mactra*

resembling the young of *M. podolica* Eichw. according to Dr. Douglas.[1]

The Upper Fars and Bakhtiari—These beds represent shallow-water conditions and strong erosion of the land masses. A thick series of reddish sandstones and marls was deposited, followed by coarser conglomeratic beds. The latter are mainly river deposits and vary greatly in character and thickness. In a general way the series shows thickening from N.W. to S.E. and also from S.W. to N.E. In the surroundings of Mosul the Upper Fars is rather thin. Towards the S.E. the thickness increases, and the Bakhtiari, which is absent around Mosul, sets in. There was a continuous change in conditions. We cannot go into details here. The following figures illustrate the changes in thickness of the Upper Fars and Bakhtiari in Iraq :—

From N.W. to S.E. :—	
Jebel Hamrin, N.W.	3,500 ft.
Jebel Hamrin, S.E.	7,500 „
Again,	
Kirkuk Anticline, N.W., at the Lesser Zab	6,360 „
Kirkuk Anticline, S.E., Tarjil . .	8,300 „
From S.W. to N.E. :—	
Jebel Hamrin, S.E.	7,500 „
Kifri Anticline (Palkanah) . . .	10,000 „

To the N.W. of Naft Khaneh Messrs. E. J. White and M. Schlumberger measured the following thicknesses :—

3. UPPER BAKHTIARI. Coarse conglomerates, sandstones, and reddish silts. The pebbles include Eocene and other limestones, and red cherts .	1100 ft.
2. LOWER BAKHTIARI. Sandstones, pebbly sandstones, and reddish silts .	4000 „
1. UPPER FARS. Reddish silts and sandstones	5200 „

[1] For revision of nomenclature, see J. A. Douglas, *Contributions to Persian Palæontology*, III (1928). This publication has appeared too late for the alterations to be included in the present paper.

The boundary between the Upper Fars and Bakhtiari is arbitrary. In the mapping in Iraq the appearance of the first pebble-beds was taken to mark the boundary.

In Persia in the region around Masjid-i-Sulaiman in the Murghab-Andakah area, Mr. H. G. Busk quotes a combined thickness of 18,700 ft. for the Upper Fars and Bakhtiari. He divides the Bakhtiari series into three parts, and gives the following thicknesses :—

UPPER BAKHTIARI. Massive conglomerates	2,000 ft.
MIDDLE BAKHTIARI. Clays, sandstones, and conglomerates, with 1500 ft. of conglomerates at base	5,500 ,,
LOWER BAKHTIARI. Clays and sandstones, with some conglomerates with gypsum pebbles	8,500 ,,
UPPER FARS. Sandstones with red shales and mudstones	2,700 ,,
	18,700 ft.

He states that there is an unconformity between the Upper Fars and the Lower Bakhtiari, and another between the Middle and Upper Bakhtiari. It is possible that the thicknesses are over-estimated.

To the S.W. of Masjid-i-Sulaiman, on the N.W. continuation of the White Oil Springs structure, Mr. J. Nason Jones and his colleagues measured a combined thickness of 7400 ft. for these groups. They give the following succession :—

3. UPPER BAKHTIARI. Conglomerates .	400 ft.
2. LOWER BAKHTIARI. Grits, clays, shales and silts, with detrital gypsum	4300 ,,
1. UPPER FARS. Sandstones and red shales	2700 ,,

They state that there is a local unconformity between the Upper Fars and Lower Bakhtiari.

In the Mishun area there is a marine intercalation in the Upper Fars. Here the Upper Fars and Lower Bakhtiari

forms a series 6500 ft. in thickness. In the Amri area Mr. Montgomery has distinguished the following stages :—

4.	Upper Bakhtiari conglomerates.	
3.	"Bad-Land" beds	3140 ft.
2.	Blue stage	2110 ,,
1.	Red beds	1250 ,,

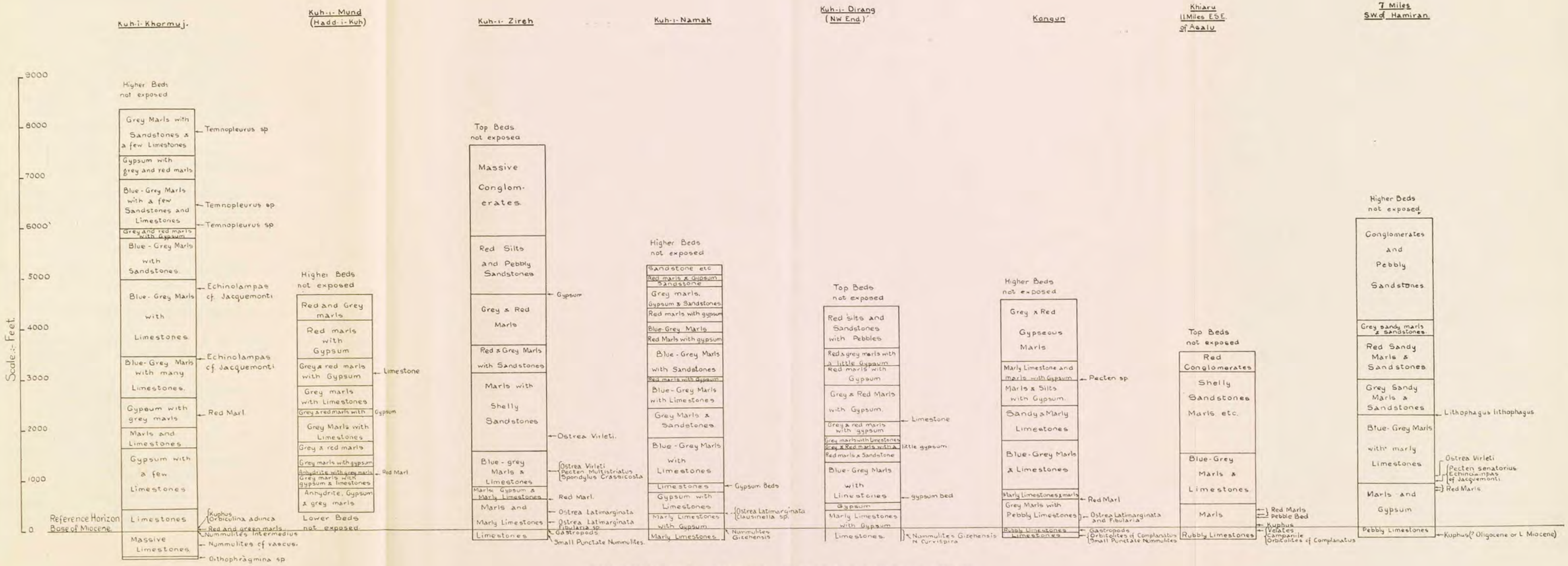
The red beds comprise red marls and clays, brown to gray sandstones, and some blue beds. *Ostrea gingensis* Schl. is found in the basal part, and celestite occurs near the base. The blue stage shows marine influence ; blue and gray marls are interbedded with pink and red beds. Limestones occur which are often fetid, or even black. *Ostrea gingensis* and *Balanus* are found in the lower part. The "Bad-Land" stage is an almost uniform succession of pale pinkish and brown silts and soft sandstones ; about 1140 ft. above its base occurs a greenish bed which shows a variation from sandstones through limestones to clays. All the above beds are gypsiferous, and on the Mishun road Ostracods occur in them.

The "Bad-Lands" stage is followed by conglomerates. The whole series is concordant. S.E. of Amri, towards the Mishun road, the red stage thickens from 1250 ft. to 1500 ft., and more oysters occur. At Amri, a gypsum bed has been observed at the base of the blue stage. This gypsum bed becomes a conspicuous feature toward the Mishun road. (Pl. XIV.)

In the coastal region around Bushire in the Kuh-i-Bang, Kuh-i-Mund, and Kuh-i-Dirang, the Upper Fars and Bakhtiari contain several groups of gypsum beds and also some marine limestones and sandstones with species of *Ostrea*, *Pecten*, and *Temnopleurus*. There are also intercalations of freshwater marls with *Unio*, *Vivipara*, *Planorbis*, and *Bythinia*.

Here again there is a striking increase of thicknesses from S.W. to N.E. In Kuh-i-Dirang the total thickness of the Upper Fars and Bakhtiari is only 2750 ft.—whereas 16 miles to the N.E. the thickness is 6100 ft., the top member consisting of 1800 ft. of massive conglomerates, which are represented by thin pebbly sandstones in Kuh-i-Dirang (Pl. X.).

Along the coast to the S.E. of Kuh-i-Dirang the gypseous type of Upper Fars and Bakhtiari passes gradually into the



STRATIGRAPHICAL COLUMNS, NEOGENE, SOUTHERN REGION

normal marine type which is found in Qishm Island and on the adjoining mainland, but never far from the present coast. The transition from a fresh-water to a marine facies is splendidly shown in the region around Bandar Abbas. Here, on the northern side of Kushk Kuh the gray silts of the Middle Fars are overlain by a great thickness of red beds succeeded by red conglomerates. On the southern side of Kushk Kuh and the Kuh-i-Siah the beds are chiefly green, gray, and brownish, with only a few intercalations of red beds; oysters of the type of *O. gryphoides* Schl. appear at certain horizons. At Konak on the southern side of the Kuh-i-Siah the following thicknesses were measured:—

Arenaceous Group.	4. Massive conglomerates . . .	600 ft.
	3. Gray sandstones with some conglomerates	800 ,,
	2. Green, gray, and brownish sandstones and silts with some red beds; *Ostrea gryphoides* Schl., *O. digitata* Eichw. at certain horizons	5500 ,,
Argillaceous Group.	Gray and greenish sandy silts with marine fauna . . .	3750 ,,

The fauna of the argillaceous group resembles that of the Middle Fars.

In the Khaneh Surkh anticline to the west of Bandar Abbas, the following sequence was measured by Messrs. Fowle and Long:—

Arenaceous Group.	3. Sandstones and pebble-beds with *Pecten vasseli* Fuchs, *Placuna* sp. and *Laganum* sp. . .	300 ft.
	2. Brownish sands, gray silts and some pebble-beds. *Pecten* (*Chlamys*) cf. *scabrellus* Lam., *Ostrea gryphoides* Schl., etc. .	2350 ,,
Argillaceous Group.	1. Gray silts with limestone-beds and marine fauna. Base not exposed	3750 ,,

Here the beds show a more marine character than at Konak.

In the Salakh anticline in Qishm Island the whole series is marine and very light in colour. The following thicknesses were measured :—

Arenaceous Group.	3. Sandstones, shelly limestones, and silts with some conglomerates, *Pecten vasseli* Fuchs, *Placuna* sp., etc.	400 ft.
	2. Sandstones, shelly sandstones, and silts, *Pecten* (*Chlamys*) cf. *scabrellus* Lam., etc. . .	1600 ,,
Argillaceous Group.	1. Gray silts and shelly marly limestones, *Pecten* n. sp. ("*præ-vasseli*"), etc. . . .	1100 ,,
	Base not seen.	[exposed.

We may point out that the boundary between the argillaceous group and the arenaceous group marks a change of facies, and cannot be used as a time-horizon.

In Biyaban, to the N.W. and N. of Jask, Mr. G. W. Halse described the Mio-Pliocene series (his "Biyaban series") as follows :—

3. Pale-coloured sands, clays and sandstones with fossils, conglomerates mostly in the higher parts . .	4000 ft.
2. Fossiliferous sandstones, limestones, clays and sands	2000 ,,
1. Pale-coloured unfossiliferous clays .	5000 ,,
Base not seen.	

He states that this series appears to be a continuation of the Makran series of eastern Makran. It is unfortunate that the faunas of the different horizons have not been worked out. All we know is that *Pecten vasseli* Fuchs occurs in a part at least of the top group.

The exact correlation of the above Mio-Pliocene series is not yet possible.

The higher part of the Lower Miocene "Asmari" limestone is Burdigalian. Another exact time-horizon is a bed

2800 ft. above the base of the Lower Bakhtiari at Khadda Zur, on the road from Masjid-i-Sulaiman to Isfahan; in this bed Dr. G. M. Lees found teeth of *Hipparion*, which he has determined as *H. gracile* Kaup. In the Jebel Hamrin, Messrs. Fowle and Hemmings found teeth of *Hipparion* sp. in the Bakhtiari. These finds mean Pliocene, so that the Lower, Middle, and Upper Fars, and the basal part of the Bakhtiari lie between the Burdigalian Asmari limestone and the Hipparion horizons of the Bakhtiari.

In the Lower Fars the Salt group marks a maximum of desiccation; the higher groups show a coming in of less saline conditions; the Middle Fars marks a marine ingression. We cannot decide whether the Salt group is Burdigalian or Vindobonian. Still less possible is a detailed correlation of the Neogene deposits of the southern Gulf area.

Finally we have to mention that the Bakhtiari show an overlap in several places. A striking example can be seen at Chal Gah, 7 miles N. of Marmatain. Here the Lower, Middle, and Upper Fars are folded up in a steep syncline pitching strongly to the N.W. These beds are overlain with violent discordance by Bakhtiari deposits which dip steeply to the N.W. across the whole width of the Fars syncline, only their basal beds showing a slight synclinal tendency.

The Bakhtiari beds show continuous unconformity and overlap throughout, but particularly in their lower part. The remaining thickness of the Upper Fars in the centre of the syncline is only 1800 ft.; then come the lowest beds of the Bakhtiari, consisting of reddish silts, derived from the Upper Fars of the syncline. Passing upwards, the silts become paler in colour, with an increasing amount of gypsum and limestone pebbles derived from the Lower Fars of the syncline, which reach a maximum about 450 ft. above the base at outcrop. Thereafter the content of derived gypsum decreases steadily, and is replaced by sand and pebbles brought from a greater distance. The thickness of the silts (Lower Bakhtiari) is here about 2500 ft., and they pass up into Upper Bakhtiari conglomerates 450 ft. in thickness. Hence in Pliocene times the anticlines were rising and were being eroded.

The Mio-Pliocene deposits have been strongly folded,

forming normal anticlines and plis-faillés. It is beyond the scope of the present paper to deal with the many interesting problems, but one thing must be pointed out; in the less strongly folded belt the distribution of the anticlines shows in many places the influence of N.N.E. to N.N.W. trends, which are probably an expression of old tectonics. The anticlines pitch down *en échelon* along these principal structural lines. Another trend cuts across these structural lines in an E. to W. direction, and coincides with the trend of some of the main synclines. A kind of rhombic disposition can be observed, of which the *en échelon* displacement is an expression. The anticlines in the folded sedimentaries appear to cover blocks of the old foundation.

THE PLEISTOCENE

The Pleistocene deposits of the regions described would provide many interesting studies; for instance the river-terraces and fans are attractive problems.

On Kharag Island the fresh-water Bakhtiari deposits are overlain unconformably by marine Pleistocene deposits, proving that the northern parts of the Persian Gulf were formed in post-Pliocene times after the Wallachian movements. The raised beaches of the Persian Gulf are another interesting problem, and we may mention that in the Kuh-i-Mund and near Tahira the Pleistocene raised beaches, which overlie the folded Bakhtiari, are tilted down towards the Gulf.

These phenomena illustrate a general principle—compression and folding, followed by breaking down.

We cannot deal further with the subject here.

PART III. THE REGION OF NAPPES

This zone has been traversed in the following places :—

1. Kermanshah to Hamadan by ourselves and others.

2. From Hamadan southwards to Khurramabad, and again for 60 miles south of Sultanabad, by Messrs. Newton and Richardson.

3. From Khurramabad to Isfahan by way of Gulpaigan and Arjanak by Messrs. Jennings and Washington Gray.

4. South-west of Isfahan along the Ahwaz road by Dr. Lees.

5. South of Isfahan along the Behbehan road by Messrs. Jennings and Washington Gray.

6. South-east of Isfahan to Deh Bid on the Shiraz-Yezd road by Mr. Washington Gray.

7. At Deh Bid by ourselves and by Messrs. Jennings and Washington Gray.

8. West of Saidabad to Niriz towards Shiraz and south of Saidabad towards Bandar Abbas, by Messrs. Jennings and Washington Gray.

9. In the Zindon range N.E. of Bandar Abbas by ourselves and by Dr. G. E. Pilgrim and by Dr. G. H. Tipper.

10. To the N.W. of Chahbar by Dr. Tipper.

11. Between Gwadar and Jalk by Blanford.

In addition Loftus traversed the country N.W. of Kermanshah along the Persian-Iraqi frontier as far north as Lake Urmia.

Section I. Kermanshah to Hamadan

In this area along the main road which connects Baghdad with Central Persia, we have the following units from S.W. to N.E. :—

1. Radiolarite Nappe.
2. Cretaceous Limestone Nappe.
3. Metamorphosed Paleozoic Nappe-group.

The total width of the nappe zone is here about 80 miles.

The front of the nappe zone is seen on the road about 7 miles W.S.W. of Kermanshah.[1] At this point Middle Cretaceous rocks of the zone of folding and shearing are over-ridden by the Radiolarite Nappe, at the base of which occurs a typical tectonic breccia.

The rocks of the Radiolarite Nappe can be divided into two parts, the lower comprising gray cherts and siliceous

[1] Upper Jurassic and Lias or Trias have been recently found S.W. of Kermanshah.

limestones, often oolitic, the upper characterised by cherts and shales of red and sometimes greenish colour. This nappe can be traced across the strike for about 30 miles to Sahneh on the main road.

Six miles N.E. of Kermanshah rises a lofty mountain range, Kuh-i-Parau, formed of the strongly folded limestones of the Cretaceous Nappe (2) (Pl. XII, fig. 2). Near Bisitun, quite close to the inscriptions, a limestone contains Rudistæ; further, a fallen block of limestone with Caprinidæ was found N.E. of Kermanshah.

The limestones end abruptly above the Radiolarite Nappe and are thrust over it in a south-westerly direction. The main road follows rather low-lying country and the exposures are not good for studying the relations of the nappes.

To the west and south-west of Sahneh and in the vicinity of Harsin serpentines occur associated with the hinder part of the Radiolarite Nappe. We were at first doubtful whether the serpentines really belong to the Radiolarite Nappe or are sheared blocks, but they form the front of the third Nappe.

At Sahneh there is a zone six miles in width, intensely folded and imbricated, comprising chlorite-schists, old black and white striped crystalline limestones, strongly dynamo-metamorphosed, and some dark limestones which may be Cretaceous.

Then the main zone of metamorphosed Paleozoic and older rocks extends back to Hamadan and beyond, a distance of 35 miles or more. The rocks in the frontal part of this zone comprise metamorphosed basic igneous rocks, chlorite-schists with epidote, and dynamo-metamorphosed black and white striped crystalline limestones; a few miles N.E. of Kangavar crinoid stems were found in one of the limestone beds. Behind them follow dark, sericitic phyllites with grauwackes, which have been intruded by the white biotite-granites of the Elwend range S.W. of Hamadan. In places the phyllite group is folded together with limestones. Some of these limestones belong to the transgressive Cretaceous. *Orbitolina* has been found in them near Nishahr 24 miles E.S.E. of Hamadan, near Shahveh 20 miles E. of Sultanabad, and at Qaqan 20 miles S. of Sultanabad. On the other hand, 14 miles N.E. of Hamadan, near the Hamadan-Kazvin road, we

found dark limestones with Cyathophyllid corals, one of which Dr. Stanley Smith suggests to be *Orionastræa* on the basis of a preliminary examination; at any rate it is Paleozoic, probably Lower Carboniferous. Much study will be necessary to determine the stratigraphy of these rocks.

The phyllite group resembles the rocks of the Grauwacke Zone of the eastern Alps and also the Paleozoics of the ore-bearing series of the northern Carpathians. But in Persia, fewer igneous rocks occur; for instance, we could find no porphyroids, only granitic and a few dioritic rocks occur.

As we have said, the phyllite group has been intruded by granites in the Elwend range S.W. of Hamadan. The granites have also been found in several places to the S.E. as far as Khuigan, 88 miles W.N.W. of Isfahan, and Loftus describes a similar association of granites and phyllites 30 miles N. of Kermanshah on the road to Sennah, and again at various points along the Persian-Iraqi frontier as far N. as Lake Urmia.

In places there are folded in with the phyllite group younger sediments derived from them. On the Musallah Hill at Hamadan, the site of the old Ecbatana, occur some softer rocks between the phyllites and the transgressive Moicene. Here Stahl collected a crushed Ammonite which he says could not be determined exactly; he refers it doubtfully to "*Arietites bisulcatus* Brug." This evidence must be accepted with reserve. Fischer, who studied Stahl's Ammonites, was not able to find the specimen in the collection.

At Kanu Dagh, 32 miles N.E. of Hamadan, occur some crushed dark shales and grits not unlike the beds on the Musallah Hill. These yielded some indeterminable Ammonites and Spatangids and are therefore Cretaceous (cf. postscript, no. 5, p. 214).

Section 2. Khurramabad to Hamadan

As we have shown, the Radiolarite Nappe is exposed over a wide area in the neighbourhood of Kermanshah, that is, in the low ground occupied by the Gamas-Ab River and some of its tributaries. Farther to the S.E. great mountains appear

and the Cretaceous Limestone Nappe seems to swing forward and over-ride the Radiolarite Nappe completely.

Certainly between Khurramabad and Hamadan there is no trace of the Radiolarite Nappe, and only the Cretaceous Limestone Nappe and the Metamorphosed Paleozoic Nappe-group can be distinguished.

The front of the Cretaceous Limestone Nappe appears near the road, about 6 miles E.N.E. of Khurramabad, where it is thrust over Lower Miocene limestone. From this point the nappe extends to the N.E. across the strike for 20 miles to the alluvial plain of Burujird. It consists of dark limestones, shattered and plentifully veined with calcite. Badly preserved fossils have been found in several places; their appearance suggests small Rudistids or Caprinidæ, and in one place a definite Rudistid was obtained. Around Razan, in the hinder part of the nappe, Eocene rocks are squeezed in between two outcrops of the Cretaceous limestone. At this place the rocks dip steeply to the S.W. and the succession from above downwards is as follows:—

6. Cretaceous limestone with Rudistids.
5. Crushed lilac and greenish shales.
4. White Alveolina limestone.
3. Pale greenish shales and thin bedded limestones, with *Alveolina* and small punctate *Nummulites* in the higher beds.
2. Red conglomerates with pebbles of red chert and dark gray limestone.
1. Cretaceous limestone, the same as 6.

On the N.E. the Cretaceous Nappe disappears under the alluvium of the Burujird Plain. On the other side of the Plain appears the Metamorphosed Paleozoic Nappe, which extends right back to Hamadan. As between Kermanshah and Hamadan, the frontal part of the nappe consists of metamorphosed basic igneous rocks, chlorite-schists and dynamo-metamorphosed striped gray and white crystalline limestones. Then follows the phyllite group which comes in a little to the N.W. of Burujird. Various rocks occur within the outcrop of the phyllite group. On the pass between Burujird and Daulatabad white granites appear, the phyllites being con-

verted into Cornubianites along the contact. To the E. and S.E. of Daulatabad rises a great synclinal mass of limestone with micaceous shales at the base; this is probably the transgressive Cretaceous. At Zamanabad, 15 miles S.E. of Hamadan, are found andalusite-mica-schists with crystals of andalusite up to 6 inches in length; it is probable that the continuation of the Elwend granite underlies these rocks. S.E. of Murad Bulagh, which is 10 miles E. of Hamadan, occur some softer rocks which may be younger than the phyllites; some of them resemble the rocks of the Musallah Hill at Hamadan.

The structure and succession of the rocks within the zone of the phyllite group have not yet been worked out.

To recapitulate, the units between Khurramabad and Hamadan are the Cretaceous Limestone Nappe and Metamorphosed Paleozoic Nappe-group.

Section 3. The Region between Khurramabad and Isfahan

In this region the following nappes are present:—

1. Nappe with normal Paleozoics.
2. Radiolarite Nappe and Jurassic.
3. Cretaceous Limestone Nappe.
4. Metamorphosed Paleozoic Nappe-group.

The first of these has been traversed only in the area between the two main branches of the Diz River, the second and third only between the S.E. end of Shuturan Kuh and Gaukun.

Shuturan Kuh is a great mountain which rises about 40 miles E. by S. of Khurramabad and runs S.E. for a distance of 25 miles. Normal Paleozoic sediments occur at the S.E. end, and it is probable that the main ridge consists throughout of the same rocks. It appears that the Cretaceous Limestone Nappe swings back from Khurramabad and runs behind this mountain. It reappears as a narrow band, together with a narrow strip of radiolarites in front of it, in the country to the E. and S.E. of Shuturan Kuh.

The nappe with normal Paleozoics, which has a width of

20 miles or more, comprises a great variety of rocks as follows :—

Limestone conglomerates of unknown age.
Lower Miocene limestones.
Eocene limestones.
Cretaceous limestones, shaley limestones and shales, and bituminous sandstones, in which Albian and Aptian fossils have been found.
The fossils so far identified are *Pseudophacoceras* cf. *roissyanum* (d'Orb), (Albian), and *Cheloniceras* (Aptian). Some crushed forms, too poor for accurate determination, resemble *Costidiscus* (Top of Barremian to basal Aptian). We are grateful to Dr. L. F. Spath for these determinations. Higher horizons of the Cretaceous are presumably present as well.
Thick black and gray limestones with Permo-Carboniferous fossils.
Red, pink, purplish and speckled sandstones and sandy shales which are overlain in the Shuturan Kuh by Permo-Carboniferous and may therefore be Devonian, although a Cambrian age is possible too.
Middle or Upper Cambrian limestone with *Dikellocephalus*.

The Paleozoics of this nappe are not metamorphosed and the Cretaceous limestones do not show the intense shattering and calcite-veining of the rocks of the Cretaceous Limestone Nappe.

From Kalian Kuh J. de Morgan collected the following fossils, which were determined by Prof. H. Douvillé ;—

Permo-Carboniferous (equivalent to the upper Productus limestone of the Salt range) :—
Black limestone with :
Pseudophillipsia cf. *elegans* Gemmellaro.
Derbya.
Spirifer (*Reticularia*) *lineatus* Martin.
Fenestella.
Phyllopora.
Rhombopora cf. *polyporata* Waagen.

Uralian (equivalent to the Middle Productus limestone of the Salt range) :—

Gray limestone with :

Lonsdaleia.
Spirigerella grandis Davidson.
Orthothetes crenistria Phil.
Streptorhynchus cf. *pelargonatus* Schl.

Black bituminous limestone with :

Fusulinella sphærica, Abich, 1858.
F. lenticularis Douvillé.
Amblysiphonia.
Michelinia.
Fenestella.
? Corbicella.

Limestone with :

Productus (*? Marginifera*) *helicus* Abich.
Spirifer (*Reticularia*) *lineatus* Martin.
Fenestella.
Nautilus cf. *tuberculatus* Abich.
Bellerophon cf. *squamatus* Waagen.

Productus striatus, Fischer, was also identified, but from which limestone is not stated, nor are the relative positions of these limestones given.

In the Tarpilla Valley which runs along the S.W. foot of the Shuturan Kuh, Messrs. R. C. Jennings and K. Washington Gray collected some material. Here they passed over the following groups, from N.W. to S.E. :—

Thin-bedded limestones of unknown age.

Hard pink and white quartzose sandstones, which are overlain by a thick massive dark limestone, which forms the great scarp of Shuturan Kuh. Boulders of limestone, believed to come from this limestone scarp, contained a spinous *Productid* (*? Strophalosia*), corals resembling *Dibunophyllum* and *Cyathaxonia*, and *? Euomphalus*.

Limestone conglomerates of unknown age.

Limestone, dipping N.E., with brachiopods, corals and crinoid stems; among the fossils are *Productus lineatus* Waagen, and a coral resembling *Michelinia*. (Identifications by Dr. Douglas.)

At Darreh Duzdan a boulder of limestone was found containing trilobites identified by Dr. P. Lake as *Dikellocephalus* (? Middle or Upper Cambrian).

From Darreh Duzdan the Permo-Carboniferous limestones extend N.E. for 6 miles to Kuh-Obarikh.

Farther to the S.E. Messrs. Jennings and Gray found steeply folded *Fusulina* limestone 4 miles N.N.W. of Baznui. From this point to Baznui and from there down the Diz River for a distance of 16 miles is a zone of steeply folded Paleozoic rocks, consisting of thick red and speckled sandstones, and black limestones which yielded *Clisiophyllid* corals and cf. *Syringopora*. To the south of Baznui the general strike of these rocks is slightly E. of N.

It has been stated that the Paleozoic limestones extend for 6 miles N.E. of Darreh Duzdan to Kuh Obarikh. Here radiolarites occur, overlain by Alveolina limestone, both of these being folded in between Paleozoic limestones. The radiolarites were seen again 15 miles to the S.S.E. at the Qaqulistan ford and from there extend as a narrow band for 15 miles in a S.E. direction. This strip is bounded on the N.E. by a high cliff of limestone, which represents the Cretaceous Limestone Nappe, extending S.E. to Gaukun. In this region the Cretaceous Limestone Nappe occupies a width of only a few miles. Then follows the metamorphosed Paleozoic Nappe-group.

Sections 4 and 5. The Region S.W. and S. of Isfahan

Here we have the following units :—

1. Nappe with normal Paleozoics.
2. Cretaceous Limestone Nappe.
3. Metamorphosed Paleozoic Nappe-group.

The Radiolarite Nappe is not seen here.

The nappe with normal Paleozoics has the same general character as in the Diz River area. It occupies a zone about

20 miles wide. It comprises Cambrian, ? Devonian, Permo-Carboniferous, Cretaceous, Eocene, Oligocene, and also younger limestone conglomerates of uncertain age.

At Narghun Dr. G. M. Lees measured the following section in the Paleozoic rocks :—

7. Blue and gray limestones with sparse gastropods and corals . . .	1000 ft.+
6. Blue and black shaly limestones .	200 ,,
5. Gray and brownish dolomites with thin sandstones with crinoids and corals	400 ,,
4. Blue limestone with *Fenestella* and *Productids* of Carboniferous (perhaps Lower Carboniferous) type . .	40 ,,
3. White, yellow and pink spotted sandstones	100 ,,
2. Gray limestones with trilobites (probably Cambrian)	15 ,,
1. Thin-bedded green micaceous sandstones	50 ,, +

It was from this neighbourhood that Loftus collected an *Orthis* stated to be a type between Silurian and Devonian. Unfortunately the specimen cannot be traced.

The nappe front runs through Do Pulan where Loftus first discovered *Loftusia persica* Carp. and Brady. Here Cambrian appears along a thrust-plane, then Nummulitic and younger conglomerates are pinched in. The Nummulitic is over-ridden by a thick Paleozoic limestone (equivalent to No. 7 of the above section) (see Pl. XV). Imbricated structure is present. A salt mountain reported in the Karun valley near here is probably extended along the thrust plane.

Farther to the S.E. Paleozoic rocks have been observed by Messrs. Jennings and Gray in a long strip along the western foot of Kuh-i-Dinar, comprising red quartzite-sandstones with purplish sandy shales and fine sandstones, dark gray dolomites with *Redlichia* sp., and other dark gray dolomites, some containing *Fenestella*, others containing spire-bearing brachiopods ; so that here again Cambrian and probably Permo-Carboniferous are present. The fossils have not yet been studied in detail. These rocks strike about N. 20° W.

It is not certain whether Kuh-i-Dinar is in the nappe zone or in front of it.

The Cretaceous Limestone Nappe, consisting as usual of thick limestones plentifully veined with calcite, appears along a thrust-plane slightly to the N.E. of the line Junagun-Buldaji. About 25 miles to the N.E. of this line follows the metamorphosed Paleozoic Nappe-group with many infolded outliers of transgressive Cretaceous limestone. Dark shales and sandstones underlie the Cretaceous limestone in places. Seventeen miles S.E. of Isfahan they yielded Ammonites and *Turrilites*, determined as Cenomanian by Dr. L. F. Spath. Four miles west of Mehiar (26 miles S. of Isfahan), were found two Ammonites resembling *Perisphinctes*; they cannot be determined exactly, but Dr. Spath remarked that they were most likely Upper Jurassic or possibly Neocomian, but in any case, not younger than Neocomian.[1]

The dark phyllite-group of the Hamadan region appears to be present, but has not yet been recognized farther to the S.E. No granites have yet been reported from this area.

The total width of the nappe zone in this region is about 80 miles.

Sections 6 and 7. The Region S.E. of the Line Isfahan—Kuh-i-Dinar

All the known occurrences of the nappe with normal Paleozoic have now been described. Farther to the S.E. the only known occurrences of Paleozoic rocks are small patches, probably associated with salt-plugs. Several of these have been discovered by Messrs. B. K. N. Wyllie, R. S. Mackilligin, R. C. Jennings, and K. Washington Gray. Trilobites of Cambrian aspect have been found a few miles S.W. of Niriz, and typical rocks of the Hormuz series have been found in the various patches. It seems that in this region the zone with normal Paleozoics broke down and was covered by the transgressive Cretaceous. N.E. of Shiraz as far as Deh Bid (on the way to Yezd), no nappe-structures can be recognized and the country is covered by strongly

[1] Dr. Douglas has recently identified a Jurassic *Trigonia* from 4 miles S. of Isfahan.

SKETCH-PROFILE ALONG CARAVAN-ROAD 60 TO 105 MILES S.W. OF ISFAHAN.

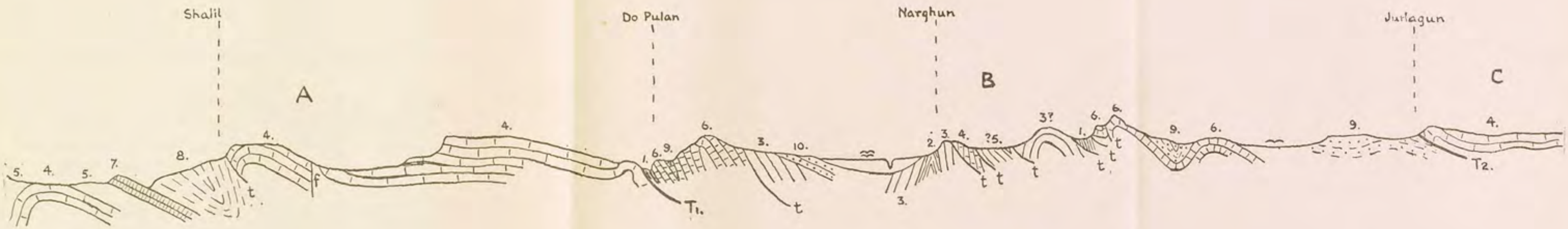
(After Dr. G. M. Lees.)

Horizontal Scale

0 — 5 Miles

Vertical Scale = Twice Horizontal.

S.W. N.E.



A. Sheared Zone.
B. Nappe with Normal Palaeozoics.
C. Cretaceous Limestone Nappe.
T1. Frontal Thrust of B.
T2. Frontal Thrust of C.
tt. Minor Thrusts.
f. Fault.

≈ Pleistocene.
10. Conglomerates, Post-Oligocene and post-thrusting.
9. Sandstones and Conglomerates, post-Eocene and pre-thrusting.
8. Fars Series.
7. Oligocene to Lower Miocene Limestone.
6. Eocene Nummulitic Limestone.
5. Cretaceo-Eocene Globigerina Marls.
4. Cretaceous Limestone.
3. Permo-Carboniferous Limestone.
2. Limestones and Sandstones, partly Permo-Carboniferous, partly Cambrian.
1. Cambrian (Hormuz Series.)

folded and faulted Cretaceous limestones.[1] Behind Deh Bid a mountain range appears, consisting of napped rocks, which extend back to the plain of Abr Quh, a distance of about 20 miles.

We made one traverse between Deh Bid and the plain of Abr Quh. On this section no radiolarites are to be seen, but near Abbasabad, 14 miles to the S.E. along the strike, the Guladar River crosses the road, bringing down many boulders of red and green chert. Red and green colours can also be distinguished there in the hills to the N.E. of the road, so that the Radiolarite Nappe should be present there.

Behind Deh Bid, a long line of Klippen indicates the frontal part of a nappe. Unfortunately the territory in front of the nappe-line is mostly obscured by extensive deposits of Pleistocene and perhaps Pliocene age. They are gravels, conglomerates, and reddish and whitish marls. The white limestone of the Klippen is strongly brecciated and squeezed.

Behind the Klippen, a short distance E. of Deh Bid, we found epidotized diabase, greenish strongly pressed sandstones containing diabase material, and lilac shales. This series is capped by yellowish limestones. Besides these there are gray and bluish Cretaceous limestones veined with calcite and containing Rudistids of the same type as on the Khurramabad section. Then come sandy phyllites and quartzites ; basic igneous rocks occur. Further to the N.E. the phyllites are overlain by a limestone complex ; certain layers of the limestone have been transformed into iron ore ; they were originally siderite containing manganese. Quartzitization has also taken place. Above these limestones follow brown limestones overlain by white limestones. The whole series is strongly folded. No fossils have been found in these rocks. A loose pebble of limestone was found containing a fossil resembling *Requienia*, which, if locally derived, would prove that Cretaceous rocks are present.

Over the above-mentioned white limestones follow strongly folded limestones and then sandy phyllites. Then comes a fault and again dark strongly folded limestones. The road

[1] Lias has been found S.W. of Yezd.

enters a broad valley and on both sides of it imbrication can be observed.

Our traverse was of a hurried nature, but we were able to establish this much, that the Radiolarite Nappe is present, also the Metamorphosed Paleozoic Nappe with Cretaceous, and perhaps also part of the Cretaceous Limestone Nappe.

Section 8. The Region W. and S. of Saidabad

In this area, the nappe zone has been traversed by Messrs. Jennings and K. W. Gray between Saidabad and Niriz to the W. and between Saidabad and Hajjiabad to the S.

At Niriz the nappe-front appears in the mountains which overlook the town on the N.E. The following groups were distinguished : radiolarites with serpentine, Cretaceous limestones plentifully veined with calcite, and a series of metamorphosed Paleozoic sediments with basic igneous rocks. To the S.W. of Niriz rises a big scarp of Cretaceous limestone which is not veined with calcite. The basal part of the limestone contains a fauna of Upper Cretaceous age which is transgressive over the radiolarites, but the section is obscured in places. If so, this would mean that the radiolarites are older than a part of the Cretaceous. About 12 miles S.W. of Saidabad appear limestones with corals, probably Permo-Carboniferous.

One hundred miles E.S.E. of Niriz, near Kukan, Messrs. Jennings and Gray found serpentines, probably belonging to the Radiolarite Nappe. Between here and Saidabad they found Cretaceous limestones with calcite veining and metamorphosed Paleozoic rocks. The metamorphic rocks were included by Dr. Pilgrim (1924) in his "Oman Series," which he shows as extending as far S. as Hajjiabad.

Section 9. The Zindon Range N.E. of Bandar Abbas

In this region we made a traverse through the nappe zone.

The great faulted anticline of Kushk Kuh runs slightly S. of E. The Nummulitic is developed in the form of Alveo-

FIG. 1.—NAPPE-FRONT, TANG-I-LOHAREE, ZINDON RANGE, S. PERSIA

A, Strongly folded Bakhtiari, covered by Terrace-gravels
B, Front of Flysch-Nappe, which over-rides A
C, Great sheared Block of Limestone with Kuphus, along thrust plane

FIG. 2.—SALT-PLUG, 12 MILES N.W. OF QUM, CENTRAL PERSIA

lina and Nummulitic limestones and Globigerina marls, with basal conglomerates which were formed around the rising anticline.

Within 3 miles eastwards of here, in the Tang-i-Loharee, rocks of an entirely different aspect are encountered along a thrust-plane which strikes slightly W. of N., *i.e.* almost at right angles to the strike of Kushk Kuh. Here typical Flysch rocks, greenish sandstones, red and green marls, dark marls, hieroglyph-sandstones and marls, often with "pencil" cleavage, are thrust over Mio-Pliocene deposits. Great isolated blocks of limestone with *Kuphus* (typical Klippen) mark the line of the thrust (Pl. XVI, fig. 1). They may be of L. Miocene or of Chattian age. The Kuphus occurs in large numbers in a block S. of the entrance to the Tang-i-Loharee.

The rocks of the Flysch Nappe are strongly folded and crumpled. In some coarse greenish grit bands in them *Alveolina* and punctate *Nummulites* occur, so that the Flysch is, partly at least, Eocene. Again lack of time prevented a closer examination of the Flysch.

The Flysch Nappe is in turn overthrust by a second nappe which we crossed on the road from Godar Surkh to Khanu and again in the Minab-Birinti gorge on our return westward. This nappe comes considerably ahead near Godar Surkh and the frontal part of it is much eroded. A gigantic, topsy-turvy medley of different rocks occurs, with serpentine, gabbro, granite, white crystalline limestone and a variety of schists—chlorite, epidote, graphite and steatite schists, and paragonite schists with disthene. These sheared blocks are intimately mingled with a sedimentary series characterized by red and green shales and cherts of the radiolarite series, and also green and gray sands, grits and conglomerates of the Flysch series. Some of the coarser beds contain *Nummulites.* Blocks of white, pink and greenish limestones also occur, and some of the white ones yielded punctate *Nummulites.*

The radiolarite series is associated with various basic and ultrabasic igneous rocks. Near Munir, on the southern side of the Rudan Valley, basic igneous rocks are seen associated with red shales and radiolarites.

The attached section (Pl. XVII) depicts diagrammatically

the structure and sequence. In general the succession appears to be a radiolarite-chert-shale series with basic intrusive and extrusive rocks. The whole series is overlain by Flysch with a basal conglomerate. Dr. Pilgrim mentions from two miles S.W. of Birinti a cream coloured limestone in which he saw a Hippurite and an Ammonite impression, so that Cretaceous seems to be present. Going eastwards the radiolarites increase in thickness. Near Guran thick jasper-like beds occur. Then come the diabases of Kuh-i-Rudan.

E. of Noti a complex of chlorite and epidote schists, crystalline limestones and serpentines is thrust over the Radiolarite Nappe.

We have here then the following units: 1. Flysch Nappe. 2. Radiolarite Nappe. 3. Nappe of metamorphic basic igneous rocks with older rocks.

This is the only part of the S.W. Iranian ranges in which the Flysch Nappe has been observed. The Cretaceous Limestone Nappe of the other areas was not encountered here; the Flysch and Radiolarite Nappes have been traced southwards as far as Dar Pahan by Messrs. Fowle and Long.

Sections 10 and 11. N.W. of Chahbar, and Gwadar to Jalk

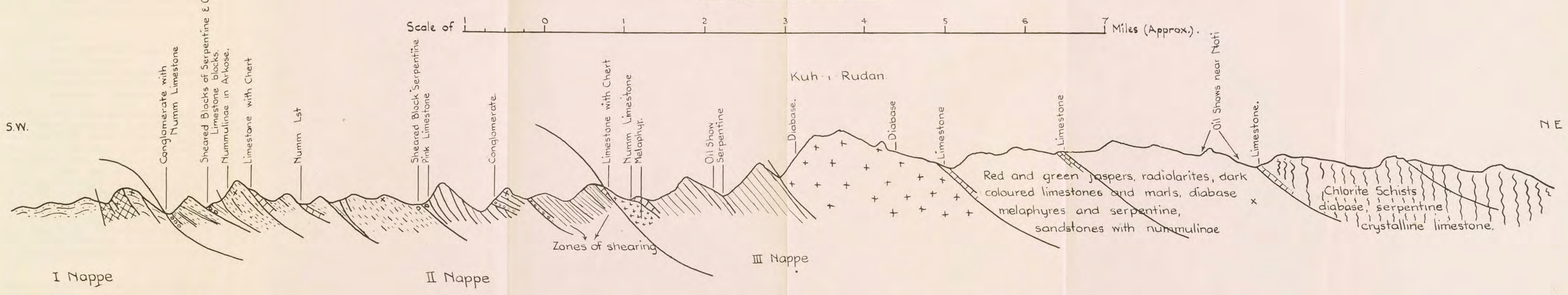
Farther eastwards, Tipper made a traverse between Chahbar and the plain of Bampur. The rocks of the Makran (Mio-Pliocene) series extend for 35 miles back from the coast. Then comes a belt 35 miles in width, composed of an intensely folded series of hardened sandstones, shales and pencil-slates, penetrated by serpentines. Behind these follows a belt consisting of altered dioritic rocks with crystalline limestones and some "altered jasperoids." It is evident that here we have again the Flysch Nappe, the Radiolarite Nappe, and the Metamorphic Nappe of the Zindon range.

The Flysch was encountered by Blanford between Gwadar and Jalk.

Summary of the Features of the Persian Nappe Zone

We have shown that in the Iranian ranges, from Kermanshah to the Zindon range, typical nappe-structures are present.

— Diagrammatic Section Showing Imbricated Structures. —
Zindon Nappes.



- Flysch Sandstone of I Nappe.
- Reddish marls and grits of above, with nummulinae.
- Red and green marls, green chert bands red radiolarites and pink coloured limestones of II and III nappe, numm Lst of III nappe.
- Conglomerate above red and green marl group
- Numm Sandstone of II Nappe.
- Limestone – X indicates presence of nummulinae
- Igneous Rocks – Diabase., Serpentine etc.
- Schists Gneiss and Crystalline Limestone.

The nappes present are as follows :—

1. An Eocene Flysch Nappe (only seen in the Zindon range and farther east).
2. A nappe with normal Paleozoic sediments, extending from the western branch of the Diz River to the country S. of Isfahan and perhaps to Kuh-i-Dinar. In this nappe the following rocks are known to occur :—

   Cambrian limestones.
   Red and speckled quartzitic sandstones.
   Permo-Carboniferous limestones.
   Cretaceous limestones, shales, and sandstones.
   Eocene, Oligocene, and Lower Miocene limestones.
   Limestone conglomerates of unknown age.

3. A Radiolarite Nappe with basic and ultrabasic igneous rocks. This nappe is concealed in places, as near Khurramabad and S.W. and S. of Isfahan.
4. A Cretaceous Limestone Nappe, formed by Cretaceous limestones, often plentifully veined with calcite. Some Eocene may be present, too, in places. It is not everywhere a separate unit but only a big imbric of the Radiolarite Nappe.
5. A nappe containing Paleozoic phyllites and older, strongly schistose igneous rocks, with transgressive Cretaceous. The phyllites are intruded by granites and are known from Kermanshah to Isfahan, but have not yet been distinguished definitely farther to the S.E.

Among these nappes the Radiolarite Nappe with its basic igneous rocks is very interesting. When we encountered it for the first time (in the Zindon range), Dr. de Böckh at once recognized its similarity to the corresponding rocks in the Dinarids.

In the Mediterranean region, in the Pyrenees and the Apennines, and then from the Dinaric Alps through the Balkan Peninsula to Asia Minor, extends a zone of interesting rocks comprising radiolarites and other siliceous shales and

basic igneous rocks, mostly serpentinized ; this complex has been called " the serpentine-ophiolite-shale-chert group " after Phillipson, who introduced this name in Greece. The igneous rocks are peridotites, harzburgites, and gabbro-like rocks. Besides these there are diabases, diabase-porphyrites, pillow-lavas, and tuffites. Many arguments have arisen about the age of these rocks, partly because of the scarcity of fossils, partly because of complicated tectonics, since these rocks occur in nappes in imbrics, often only in tectonic contact with other rocks, partly because there are older igneous rocks of similar habit. Kossmat has discussed these questions in his *Geologie der Zentralen Balkanhalbinsel*, Berlin, 1924.

In the Balkan Peninsula the complex is overlain in several places by basal conglomerates of the Gosau facies of the Upper Cretaceous, and in Albania (Mali Senjt in Merdida), Vetters found in shales overlying serpentine and gabbro-conglomerates, *Phylloceras infundibulum* d'Orb. and *Crioceras duvalii* Lev. ; so that here the complex is evidently older than Cretaceous.[1]

It is evident from the above that from the Pyrenees and the Apennines through the Alps and the Balkans into Asia Minor there goes a zone of femic rocks which, according to our discoveries, extends far to the east. The most easterly point at which we found them is the Zindon range, while Dr. Lees found them again in Oman. The determination of the age is rather difficult. But after reading Kossmat's paper, there seems to remain little doubt that in the Balkan Peninsula the radiolarite-chert-shale-ophiolite group is of Jurassic age, and that there may exist an older similar group which is comprised of melaphyres, porphyrites, felsite-porphyrites, tuffites, shales and cherts, which is probably of Ladinian age. This older group does not contain peridotites.

In Iraq and south-western Persia, the Bakhtiari (Pliocene) beds and the Eocene and Cretaceous sandstones and conglomerates of the autochthonous folded zone, contain pebbles and débris of rocks which match the series in question, and as we have pointed out, the radiolarites may possibly be

[1] H. Vetters, " Geologie des nordlichen Albaniens," *Denk. K. Akad. Wiss. Wien., Math. Nat. Kl.*, Vol. LXXX (1906).

overlain by Upper Cretaceous limestone to the S.W. of Niriz.

In the Zagros ranges, neither Trias nor Jurassic have any great proved extension.[1] In the Median Mass Tipper found Liassic in the Kuhistan district near Kirman ; it is a shallow water facies ; plant remains and coal occur. However, in the Elburz the Jurassic is better developed.

We shall see that the same neritic facies of the Paleozoics, which occur in the folded zone and in the frontal nappe zone of the Diz River-Isfahan region, are found also in the Median Mass. It would appear that in late Jurassic or early Cretaceous times there was formed a deep trough, the Iranian geosyncline, which was filled up in Cretaceous and Kainozoic times. Perhaps it was at the time of the formation of this trough that the radiolarite-chert series and the accompanying ophiolites were formed (cf. postscript, no. 6, p. 214).

In the above pages we have only given the evidence which establishes the presence of nappes. Much has yet to be done, and it is possible that a detailed study of the nappe region would prove that the nappe zone is formed by a series of big geanticlines which have been transformed into plis-faillés on a gigantic scale. The metamorphosed Paleozoics in the surroundings of Isfahan and Hamadan dip rather gently towards the Median Mass, and it seems that it is only the frontal parts of the big geanticlines which form the thrust sheets (see p. 161 in the conclusions).

It is evident that when the geanticlines are moving the crestal parts will go ahead and here the oldest rocks will be exposed ; whereas towards the plunging ends, younger and younger rocks will appear. The regions where the Radiolarite Nappe is missing may correspond to areas which have been originally saddles between the big geanticlines ; and here the Cretaceous rocks alone are encountered, the older Radiolarite Nappe having been covered by them.

PART IV. THE MEDIAN MASS

Passing behind the zone of nappes, we enter a country of a very different character. A glimpse at Stahl's maps shows

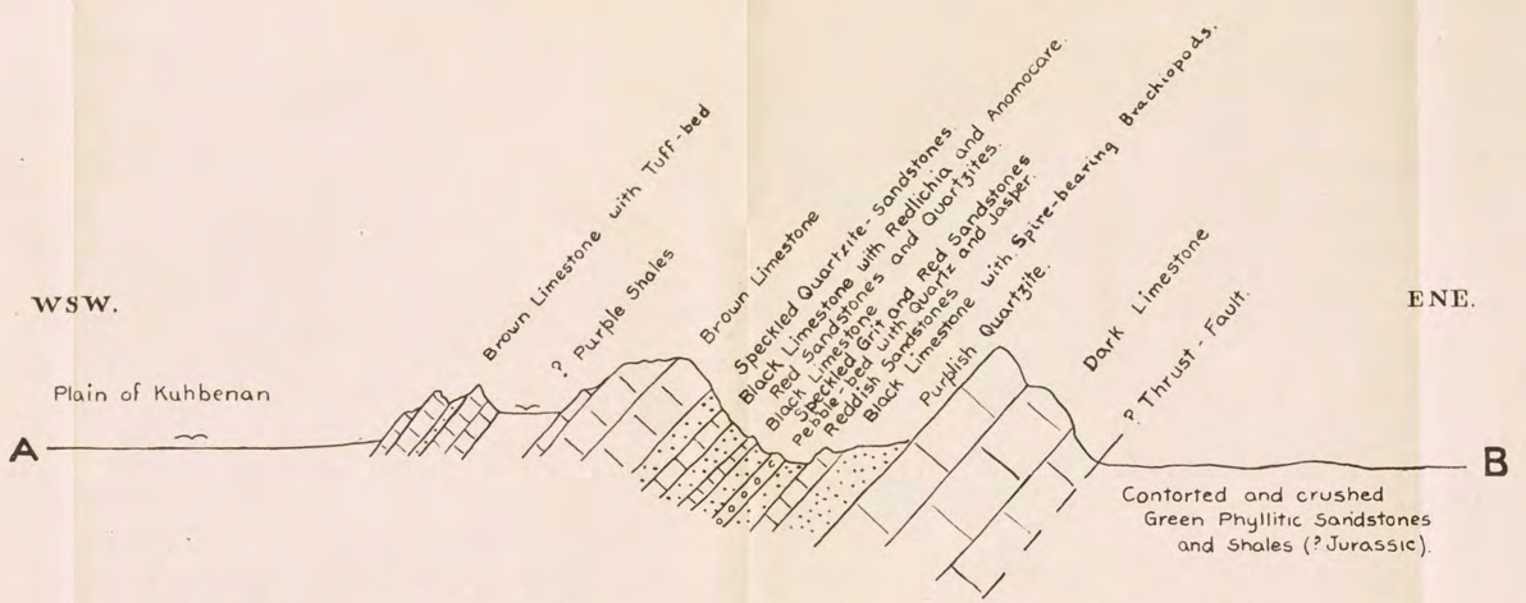
[1] Continuous sedimentation began only with the Cretaceous.

ranges which have in their cores rocks of various ages. Between the ranges lie wide plains, big basins filled up with Kainozoic and younger deposits. The oldest rocks are old crystalline schists and igneous rocks. They are overlain by Cambrian. Messrs. Jennings and Gray collected fossils from a limestone at Kuhbenan, 90 miles N. 30 W. of Kirman. We recognized typical Cambrian trilobites, and Dr. Cooper Reed and Mr. W. B. R. King have been good enough to confirm our determinations of *Redlichia* sp. After a closer examination, Mr. King has written that it appears to be very near *R. noetlingi* Redlich, *R. nobilis* Walcott, and *R. chinensis* Walcott. With them occurs a trilobite of *Anomocare* type, so that the limestone is probably of Middle Cambrian age. The trilobite limestone is associated with speckled sandstones.

The descending sequence given by Messrs. Jennings and Gray is as follows (see also Pl. XVIII) :—

Brown limestone with tuff-bed.
? Purple shales (concealed by alluvium).
Brown limestone.
Speckled quartzite-sandstones.
Black limestone with the trilobites.
Red sandstones and quartzites.
Black limestone.
Speckled grit and red sandstones.
Pebble-bed with quartz and jasper pebbles.
Red sandstones.
Black limestone with spire-bearing brachiopods.
Purplish quartzite.
Dark limestone.
? Thrust-fault.
Intensely contorted greenish phyllitic sandstones and shales with lamellibranchs (? Jurassic).

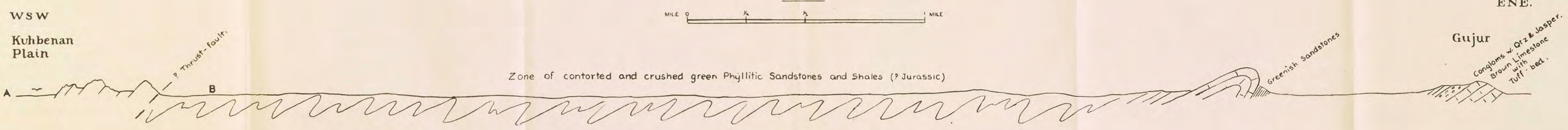
There is no doubt that the succession is an abnormal one. It is an important feature that a shallow-water and littoral facies of the Cambrian is present here. In Cambrian times a shallow sea extended right across the site of the present Zagros Mountains. It is also noteworthy that these Cambrian deposits are not at all metamorphosed.



PALAEOZOIC OUTCROPS NEAR KUHBENAN, ENLARGED TO SHOW DETAIL.

Scale

MILE 0 ¼ ½ 1 MILE



DIAGRAMMATIC SECTION BETWEEN PLAIN OF KUHBENAN AND GUJUR

SHOWING FOLDING TOWARDS E.N.E., I.E. TOWARDS THE DASHT-I-LUT DEPRESSION

AFTER

MESSRS. R.C. JENNINGS & K. WASHINGTON GRAY.

Scale

MILES 0 1 2 3 4 5 MILES.

After the Cambrian, the oldest deposits known are of Devonian age. Stahl found near Soh, 56 miles N. of Isfahan, Middle Devonian with *Waldheimia whidbornei* Davidson, *Rhynchonella elliptica* Schnur, *Nyassa dorsata* Goldfuss, and *Paracyclas rugosa* Goldfuss. He remarks on the absence here of the Old Red Sandstone facies of the Elburz. At the same place he found the Permo-Carboniferous with *Spiriferina cristata* Schl., *Eumetria indica* Waag., *Athyris* cf. *roissyi* Leville, *Athyris* cf. *lamellosa, Terebratula vesicularis* Koninck, etc.

The same author mentions Upper Devonian from 21 miles N. of Kirman on the road to Ravar between the caravanserai Abbid and the village Serash. Here a dark limestone which overlies diorites yielded *Spirifer archiaci* Verneuil, *Tentaculites* and Crinoids.[1]

At Kuh-i-Badamun, 22 miles W.S.W. of Kirman, Messrs. Jennings and Gray found a limestone with *Spirifer*. In the same region, Tipper,[2] found Carboniferous at Hutk between Sar-i-Asiab and Hizumi and again 2 miles N.E. of Hizumi. He mentions that Pilgrim found several *Productus* there. The fauna described does not allow exact zoning.

Besides these occurrences Stahl mentions shales, phyllites, and grauwackes near Zefre on the road from Isfahan to Nain and again from the road between Niastanek and Pakuh. These rocks may be Cambrian or younger Paleozoic.

Taking all these scattered observations into account, we are able to say that in the Median Mass we have Middle Cambrian overlying old rocks. Then comes a gap. Middle and Upper Devonian are present. Whether there is a continuous sequence containing Devonian and Carboniferous or whether there is another break between them we do not know.

During these periods the deeper sea lay to the N. whereas southern and western Persia and the western and southern parts of the Median Mass were only flooded at intervals by a shallow sea. No alpinotype movements occurred. Only along the site of the Zagros Mountains does there seem to

[1] A. F. Stahl, "Zur Geologie von Persien," *Pet. Mitt., Ergänzungsheft*, No. 122 (1897), p. 63.

[2] G. H. Tipper, "The Geology and Mineral Resources of Eastern Persia," *Rec. Geol. Surv. India*, Vol. LIII, Part I (1921), pp. 55-6.

have been a deeper part where the Paleozoics were folded by Hercynian movements.

The Trias is unknown, apart from certain fossils found at Naiband, which Dr. Douglas believes to be of Triassic age.[1] In Jurassic, or perhaps Rhætic, times a new transgression took place. In northern Persia (in the Elburz) the Jurassic is rather well developed.

Tipper describes the following sequence in the Kuhistan district around Kirman (l.c. p. 57):—

6. Red grits, shales, and conglomerates.
5. Green shales, grits, and conglomerates with plant remains.
4. Violet shales with thin limestone bands.
3. Brown sandy limestones.
2. Thicker-bedded gray limestones.
1. Thin-bedded black limestones.

He quoted from bed 3, forms which seem to indicate an Upper Liassic age. This series is folded and is overlain by Hippuritic limestones. Beds corresponding to the above sequence contain coal in several places (cf. postscript, no. 7, p. 214).

Further observations have been made by Mr. J. Nason Jones in the mountains E. and S.E. of the Daria-i-Namak (Salt Lake) in the Dasht-i-Kavir. Here, in the Kuh-i-Hashimabad anticline, he found phyllites and mica-schists which are penetrated by granite dykes. Besides these he describes aphanitic lavas, melaphyres and trachytes, with granites, exposed to a depth of about 1500 ft.

To the W., S.W., and S. of Kuh-i-Hashimabad lies a big faulted anticlinal system (Kushk Kuh, Kuh-i-Yakh Ab, Kuh-i-Garm Ab, Kuh-i-Khark-i-Shahi, Kuh Sangao, Kuh-i-Tausova, and Kuh-i-Tulha Gamal). Hence he describes phyllites and mica-schists with quartz-veins; diabases, melaphyres, aphanitic lavas, trachytes, porphyrites, and granites are also mentioned. These igneous rocks are overlain by limestones. In Kuh-i-Safid Ab, where the same

[1] Dr. Douglas has recently identified Upper and probably Middle Trias, and probably Rhætic, from Naiband, and Upper Jurassic from Gujur and from S. of Ravar; also Lias near Yezd (Jennings-Gray collection).

igneous rocks occur, the limestones contain ammonites and are apparently Cretaceous.

The phyllites and mica-schists are probably very old. The igneous rocks, being older than Cretaceous, may be equivalents of the igneous rocks which penetrate the Cambrian of the Persian Gulf and are overlain by Cretaceous. Perhaps they are in some way related to the basic rocks of the Radiolarite Nappe.

The Cretaceous is everywhere transgressive. The oldest known rocks are found near Yezd in the Shir Kuh, from where Fischer determined *Requienia* sp. At Soh, 56 miles N. of Isfahan, *Parahoplites melchioris* Antula has been found, (top of Aptian, or base of Albian). From Anarek, Cenomanian and Turonian fossils have been described. At Lahr Surkhet *Pycnodonta proboscidea* d'Archiac (Santonian) has been found; at Madar-i-Shah, 64 miles N.N.W. of Isfahan, *Exogyra matheroniana* d'Orb. which indicates Campanian; and Rudistid limestones from many places, but the fossils are not yet determined.

The Cretaceous is more fully developed farther to the N.W., as in eastern Armenia, where all stages from Valanginian to Aptian are found; again in the Elburz where Stahl found the Neocomian forms *Acanthodiscus* cf. *vaceki* Neum.-Uhlig, and *Hoplites* cf. *rutimeyeri* Ooster, and also in Iraq to the N.W. of Sulaimani in the folded zone, where, as we have mentioned, Valanginian is known.

In Cretaceous times a typical geosyncline was formed to the south-west of the Median Mass and from this geosyncline and from Armenia, ingressions of the sea took place, flooding the Median Mass.

Our knowledge of the igneous rocks in this zone is very limited, and further studies are needed to establish their history.

Dr. de Böckh made some observations on the Hamadan-Kazvin road. To the N. of Ab-i-Garm, near the Khar Rud, Cretaceous limestones with very large *Inoceramus* are overlain by thick conglomerates. Farther S. on the N. side of the Sultan Bulagh Pass, phyllites are overlain by Middle Eocene conglomerates with *Nummulites perforatus A* and *B*, de Montfort.

These conglomerates do not contain igneous rocks. Higher in the Eocene series tuffs appear and these develop more and more as one goes higher in the series. The sedimentary series is overlain by thick volcanic agglomerates, tuffs, and lava-flows, and is penetrated by andesitic and more acid rocks, *e.g.* granodiorite. The volcanic rocks are overlain by Aquitanian deposits which transgress over them and over older rocks, beginning with a basal conglomerate.

Near Chashmeh Ali, S.W. of Qum, Messrs. H. C. G. Newton and F. D. S. Richardson observed the following sequence :—

3. Lower Miocene limestone with *Kuphus*.
2. Red and purple conglomerates, sandstones, and sandy shales, with coarse basal conglomerates.
1. Olive and green shales and fine tuffs of the Eocene.

In the lower part of Group 1 there is a thin band of limestone with *Nummulites perforatus B*, de Montfort, *N.* cf. *millecaput* Boubée, and *Orthophragmina*.

The Paleogene igneous rocks are also well developed in the Elburz. There is also a younger igneous series in the Median Mass. Around Rahgird, 65 miles W.S.W. of Qum, the red, sandy Neogene deposits which follow above the Miocene limestones, are overlain by a great thickness of agglomerates, tuffs, and lava-flows. The sandy series and the agglomerates are penetrated by andesitic and basaltic dykes running roughly N. and S. Typical volcano-ruins are present here. Dykes similar to the above occur a few miles farther E., between Qum and Chashmeh Ali, and here there is also a volcanic agglomerate interbedded with the younger Kainozoic sediments. N.W. of these places, at Khumaigan, 100 miles N.E. of Hamadan, there is a considerable thickness of tuffs. These rocks are very young.

It seems that in Paleogene times there was a volcanic girdle surrounding the Median Mass on the N. and W. In late Neogene times and in the Pleistocene, a younger girdle was formed.

The Paleogene igneous series is also present in the Dasht-i-Kavir country. It occurs in the E. to W. anticlines of Siah-Kuh, Kuh-i-Arabiyah, Kuh-i-Tulha and Kuh-i-Safid Ab, and in the big anticlinorium of Kushk Kuh, Kuh-i-Yakh Ab, etc.

In Kuh-i-Safid Ab and Kuh Chah Gobad, dolerite dykes cut across Cretaceous limestones according to Mr. Nason Jones. These should represent the younger volcanics. The pre-Cretaceous igneous series seems also to be present, according to his description.

From S.E. Persia igneous rocks have been described by Stahl, Tipper, and Pilgrim. Pilgrim describes the Dukhtar series from S. of Bahramabad. He says that cream-coloured shales and siliceous limestones are penetrated by basic lava-flows and dykes. These basic lavas are overlain by agglomerates, ash-beds, and acid lavas. Then follow fine tuffs. The whole series is penetrated by intrusive diorites which he calls the Panj Intrusive series.

Tipper (l.c. p. 61) described ash-beds, agglomerates, and lavas, penetrated by porphyrite dykes, from the ranges of Jamal Bariz and Kuh-i-Shah Savaran. He also mentions fine-grained banded tuffs of rhyolitic character, and at Abariq basic lava-flows, probably olivine-basalts. The fine tuffs rest unconformably on Rudistid limestones which yielded *Sphærulites* sp. at Abariq. He correlates these rocks with some volcanic tuffs and agglomerates described by Vredenburg from the Baluchistan Desert (l.c. pp. 195-7), and assigns them an Upper Cretaceous age.

In 1922, Mr. Malcolm Maclaren visited the Bahr Asman Mountains, 75 miles to the S. of Kirman. There he found tuffs, breccias, and lavas; this series is penetrated by dykes of basalt and augite- to hornblende-porphyrites. The more acid of these rocks are associated with copper occurrences. We may remark that copper is very widespread in this older igneous series. He says that bedded basalts are conformably overlain by highly fossiliferous Nummulitic limestones and concludes that the basaltic series is Cretaceo-Tertiary and probably nearer in age to the overlying Eocene than to the underlying Cretaceous. The fossils of the " Nummulitic " limestone are not named.

In the Oman range, Dr. Lees found lava-flows interbedded with Maastrichtian deposits. These southern occurrences may therefore be somewhat older than those in the north-west, but it is quite clear that there is an older Neocretaceous-Paleogene phase and a younger Neogene phase of volcanic

activity. All the above-mentioned igneous rocks await thorough study.

Recent igneous rocks are also known. Tipper (l.c. p. 69) mentions recent lavas (olivine-andesites) from near Dehan Abbas Ali, and Blanford described young volcanic cones from the Namashir Plain. Vredenburg collected the same rocks at Batil Kuh and MacMahon from the Afghan-Baluchi boundary.

Before turning to the study of the Neogene, we wish to point out that in places the Eocene is developed in a Flysch facies. Near Digtash, on the S. flank of the Elburz, occurs strongly folded Eocene Flysch with characteristic tuffs. In Dasht-i-Kavir (Kushk Kuh), Mr. Nason Jones found a coarse sandstone containing *Nummulites perforatus B*, de Montfort.[1] Far to the S.E., near the Persian-Baluchi boundary, Mr. K. Washington Gray found Eocene Flysch with large punctate Nummulites cf. *N. perforatus B.*, de Montfort, on the Lakshak Pass, between Duzdab and Dahni-Baghi.

The Neogene Deposits

Wherever we could study them in the more northern areas, we found the Neogene deposits transgressing over the Paleogene igneous series and older rocks. To the E. and S.E. of Hamadan we found them transgressing over the Paleozoic phyllites. In the Kanu Dagh, 32 miles N.E. of Hamadan, they lie unconformably above Cretaceous. In the Hill 7550 on the ½-inch map No. 9 E. (S.W.) of the Indian Survey, 4 miles S.W. of the Sultan Bulagh Pass, they overlie the Paleogene igneous series. At all these places they begin with a strong basal conglomerate. The same is the case at Husseinabad, 49 miles S.W. of Kazvin, and again near Semnan.

The development of the Neogene series (which may include some Oligocene deposits too) is very variable.

Where fully developed the series can be divided as follows :

3. Group corresponding in a general way to the Fars and Bakhtiari.
2. Marine group.
1. Basal red group.

[1] Identification by Dr. Douglas.

Group 1. The Basal Red Group

This group rests unconformably on older rocks. It comprises red marls and dark red sandstones with thin gypsum beds and gray and greenish marls, coarse, pebbly sandstones and conglomerates. The thickness varies greatly, from a few feet to several hundreds. The deposits are very saliferous and the salt-plug 12 miles N.W. of Qum may have arisen from this group (see Pl. XVI, fig. 2).

The group can be studied around Qum and to the S.W,. and again between Aivanikaf and Semnan. At its base lateritic deposits were observed in many places, indicating that the underlying rocks have been exposed to weathering for a long time.

Group 2. The Marine Group

This group also varies greatly in thickness. The rocks are sometimes more calcareous, sometimes more sandy. Limestones play an important rôle.

Near Qum, the following sequence was observed :—

7. Greenish and whitish marls with *Pecten tietzei*	*ca.* 750 ft.
6. Gypsum, greenish and whitish marls and limestone	250 ,,
5. Red, gray and yellow sandy marls and sandstones	200 ,,
4. Pale saliferous marls with limestone beds	400 ,,
3. Limestones and marls with *Lepidocyclina elephantina* Mun.-Chalm. .	350 ,,
2. Gray sandy marls with some sandy limestones and sandstones . .	850 ,,
1. Greenish sandstones and sandy limestones with *Scutella* sp. . . .	300 ,,
Lower red Group 1.	
Thickness of marine group .	3100 ft.

At Abshilina near Hamadan, the lower red group is about 760 ft. thick and the marine group about 750 ft.

At Semnan, the thicknesses are as follows :—

Group 2.	Limestone	310 ft.
	Yellowish marls, thin limestones and sandstones .	130 ,,
Group 1.	Reddish sandstones and pebbly sandstones . . .	300 ,, (exposed).

Near Awaj, 4 miles N.E. of the Sultan Bulagh Pass, Group 2 contains Globigerina marls. In the surroundings of Kazvin, Group 2 could not be observed.

Group 3. Beds Corresponding to the Fars and Bakhtiari Deposits of S.W. Persia

Above Group 2 come bluish or grayish marls with gypsum. Then follow red marls, sandstones, and pebbly beds.

Near Semnan, Dr. de Böckh and Mr. H. T. Mayo measured the following thicknesses above Group 2 :—

4. Sandstones	1200 ft. (exposed).
3. Pale buff marls with two impure gypsum beds about 300 ft. from the top	550 ft.
2. Reddish marls with selenite . .	2200 ,,
1. Reddish marls alternating with 2-3 ft. beds of gypsum, also gray marls .	1550 ,,
Thickness of Group 3 . .	5500 ft.

In the surroundings of the Alkadar River to the S.W. of Teheran, the following sequence is exposed :—

5. Sandy marls, pebbly beds, and selenite.
4. Sandy marls and pebbly beds.
3. Red, bluish and greenish marls.
2. Sandstones and reddish marls.
1. Red and gray marls with gypsum and salt.

Here the highest member looks like Lower Fars from a distance.

Near Najafabad, 13 miles N.N.E. of the Sultan Bulagh Pass, Groups 3 and 5 attain a thickness of 15,000 ft.

We do not find the Neogene deposits developed everywhere. For instance, near Aga Baba, 15 miles W.N.W. of Kazvin, the Paleogene igneous rocks are overlain by about 1000 ft. of gravels, the lower beds being absent.

The various synclines did not all subside at the same time and each big synclinal area has its own particular history. Only to the S.W. of Teheran and in the surroundings of Qum are more uniform conditions present.

In the ranges N.E., E., and S.E. of the Daria-i-Namak in Dasht-i-Kavir, similar conditions prevail. In the cores of the anticlines a Miocene limestone and marl group overlaps the Paleogene igneous rocks. A basal conglomerate can be observed. In places, as in Siah Kuh, the limestones contain beds of gypsum. Then follow unfossiliferous green, pink and white marls and calcareous sandstones with occasional thin limestone beds. Above them follow unfossiliferous red sandstones and marls and then fine-grained, ill-cemented sandstones and saline silts, alternating with thin Flysch-like sandstones, marls, grits and occasional thin limestone bands with *Chara* and ostracods. Veins of secondary gypsum are common.

Salt-plugs are known to occur near Qum and in Kuh-i-Gugird. The plug 12 miles N.W. of Qum, which is about 1 mile across, is pushed up through rocks belonging to Group 3. The rocks of the plug itself consist of salt and dark red saliferous sandy marls with gypsum and some gray marls; augite-andesite is also present. It is not known for certain whether these rocks belong to Group 3 or the basal red group 1, but on the whole they rather resemble the latter, which does contain some igneous rocks in this neighbourhood.

On the S. flank of Kuh-i-Gugird there are five plugs of salt and gypsum. The largest of these has an area of about 5 square miles. Near Lasgird, about 20 miles farther N., there is a large development of gypsum and here occurs *Ostrea* cf. *fimbriata*, Grat., which has some resemblance to

O. latimarginata, Vredenburg. Dr. J. A. Douglas considers that it may be a forerunner of *O. latimarginata*. In this area the salt-plugs have apparently arisen from the group with salt and gypsum which overlies the marine Group 2. Mr. Nason Jones points out that the salt in Kuh-i-Gugird does not bring up any igneous material, whereas the Qum plug contains augite-andesite. This may, however, belong to the younger Neogene volcanic series, but, as has been suggested, the Qum plug may have arisen from the lower red group. Mr. Nason Jones has observed the thicknesses shown in table on opposite page in the area to the E. of the Daria-i-Namak.

Fuchs studied the fauna collected by Tietze from the Siah Kuh, S.E. of Aivanikaf, and assigned to it an Aquitanian and Burdigalian age. Since that time *Flabellipecten burdigalensis* Lam. has been collected from several places, *e.g.* from Semnan, from Kuhni Dagh between Qum and Kashan, and from Ain el Rashid in the Siah Kuh, so that the presence of Burdigalian is well established.

Von Niedermeyer has given a description of the " Binnenbecken " of the Iranian Highlands. We do not enter here on a discussion of these synclinal areas. The important facts are as follows. The older rocks were overlapped by Cretaceous and Eocene. Then came a period of great volcanic activity. The Paleogene volcanics and all older rocks were apparently folded into " Great-folds " (the " Grossfalten " of Abendanon), the ranges showing a remarkable adjustment to the directions of the orogen, running N.W. to S.E. on the Zagros side and E.W. on the Elburz side. Then came the Aquitanian overlap and a new cycle of sedimentation set in.

The subsiding synclines were filled up. In some of the deeper basins, as near Najafabad, the Kainozoic rocks were first folded and then followed a general breaking down and faulting.

The subsidence of the synclines, which may be compared with W. Penck's " Ova "-structures, causes overfolding round their margins. The overfolding, which results even in plis-faillés, is directed towards the interior of the great depressions. The direction of movement is north-eastwards on the Zagros side, as has been observed near Qum and

Age.	Kuh-Dwazdeh Imam.	Siah Kuh.	Kuh-i-Tulha.	Kushk Kuh Area.	Kafar Kuh.	Kuh-i-Chah Shur.
Pliocene to L. Miocene.	Sandstone and marls, 1000 ft.	Sandstones and marls with gypsum veins, 10,000 ft.	Sandstones and marls, 6000 ft. +.	Buff-coloured sandstones and red marls, 2000 ft. +.	Sandstones and marls, 1000 ft. +.	
Lower Miocene.	Limestones and marls with *Ostrea fimbriata* Grat., *Flabellipecten expansus* Sow., etc., 750 ft.	Limestones and marls. *O. fimbriata* Grat., *F. expansus*, Sow., *F. burdigalensis* (Lam.), 2000 ft.	Limestones, some gypsum, 700 ft., increasing to 1800 ft., 10 miles further S. Conglomerates.	Limestones and marls. *O. fimbriata* Grat., *O. virleti* Desh., etc., 300 ft. +.	Limestones and gypseous marls. *O. fimbriata* Grat., *Flabellipecten burdigalensis* (Lam.), 1800 ft.	Limestones and marls. *O. fimbriata* Grat., *F. burdigalensis* (Lam.), etc. Basal conglomerates of igneous boulders, 450 ft.
Eocene.	Quartzites, trachytes, andesites, tuffs, etc., 2000 ft. +.	Trachytes, andesites, tuffs, etc., 3000 ft.	Lavas, tuffs, etc., 3500 to 4000 ft.	Lavas, tuffs, etc., 8000 ft. + Cretaceo-Eocene limestones. *Nummulites perforatus A.* and *B.* in sandstones, 1400 ft.	Trachytes, tuffs, etc., 400 ft. +.	Lavas, tuffs, etc., 900 ft. +.

again 20 miles to the S.E. of Yezd, and southwards on the Elburz side, as in the mountains to the E. of the Daria-i-Namak.

No Alpinotype movements are known in the Median Mass.

We have not enough data to establish a canon of the movements and we can only say the following.

The oldest movements were pre-Cambrian; the Cambrian overlaps on to an old eroded surface. Then epeirogenetic movements seem to have prevailed. The Paleozoic, Triassic and Jurassic seas flooded the old surface from time to time.

The Cretaceous is transgressive and overlaps on to an older igneous series which may be an equivalent of the "Hormuz" intrusives and extrusives in the salt-plugs of the Persian Gulf.

Towards the end of the Cretaceous, movements took place marked by unconformity. New volcanic activity set in at the end of the Cretaceous and in the Paleogene.

Then came the Aquitanian transgression. Folding commenced, and apparently became very strong in the late Pliocene, corresponding to the Wallachian movements of Stille. Then breaking-down took place and another cycle of volcanic activity set in.

PART V. OMAN

By Dr. G. M. Lees

The Oman mountain arc, with its ranges rising to nearly 10,000 ft., is obviously a foreign element on Arabian soil, and its essential connection with the Zagros Mountains of Persia was first recognized by E. Suess. He assumed a "Scharung" at Bandar Abbas and treated Oman as a simple outer loop rejoining the mainland structures at Cape Monze, W. of Karachi, the intervening portion having subsequently broken down. This interpretation has been followed by Blanckenhorn, Argand, and Krenkel, but the recent investigations of Messrs. Lees and Gray have shown that the problem is not so simple as had been assumed. Oman has been subjected to two phases of movement, the more intense one being of pre-Gosau age. Great overthrusts or nappes were formed at this time (cf. postscript, no. 8, p. 214).

Stratigraphy

10. *Miocene*—Conglomerates, sandstones and coal-bearing shales. Fossil evidence of age is lacking, but stratigraphical position indicates Miocene.

9. *Oligocene*—Not identified, but probably present.

8. *Eocene*—Lower Eocene has not been identified with certainty but may be present, as in many places the uppermost Cretaceous is conformably overlain by massive limestones. In Sharqiyah the belemnitoid form *Styracoteuthis orientalis* Crick, found by Dr. Jayakar, is probably of Lower Eocene age. In many places, *e.g.* in the vicinity of Muscat and on Masirah Island, Middle Eocene is transgressive on older rocks. Pilgrim has recorded the following Nummulinidæ from the former locality, *N. atacicus* Leym., *N. globulus* Leym., *Assilina granulosa* d'Arch., and Lees from the mainland behind Masirah Island, *N. gizehensis* Forskal, and *N. obesa* de la Harpe. These beds seem to occupy an intermediate position between the Egyptian Mokattam horizon and the Indian Kirthar. The fossil collection of Messrs. Lees and Gray has not yet been worked out in detail and from the present knowledge a more exact zoning of the Eocene is not possible.

7. *Upper Cretaceous*—On the western side of the Oman ranges Maastrichtian rocks are transgressive on the older folded complex of Paleozoic to Lower Cretaceous. They are very fossiliferous, containing among others the following forms :—

Lepidorbitoides socialis Ley.
Omphalocyclus macropora Lam.
Loftusia morgani Douvillé.
Loftusia persica Carp. and Brady.
Ostrea ungulata Schloth.
Ostrea overwegi von Buch.
Plicatula hirsuta Coq.
Lucina dachelensis Warner.
Nerinea ganesha Noetling.
3 species of *Cyclolites*.

At Sireir (on the mainland behind Masirah Island), the limestones and marls yielded a Senonian (Campanian) fauna :—

Ostrea villei Coq.
Salenia cossiœa Cott. et Gauth.
Coptodiscus noemiœ Cott. et Gauth.
Conulus triadis Lees.
2 species of *Diceras*.

At Murbat in Dhofar Cenomanian limestones and marls unconformably overlie a desert sandstone formation. They contain *Vola quadricostata* Sow., *Salenia scutigera* Gray, *Orbitolina concava* Lam., etc.

6. *Lower Cretaceous and Jurassic*—The Ruus al Jibal, the northern extremity of the Oman Peninsula, is formed of a massive 5000 ft. limestone formation, the Musandam limestone, the upper beds of which have yielded a Neocomian (? Barremian) fauna with the following forms :—

Ostrea diluviana Linn.
Hinnites renevieri Pict. and Camp.
Pholadomya gigantea Sow.
Venus galdrina d'Orb.
Nerinea archimedis d'Orb.
Harpagodes desori Pict. and Camp.
Heteraster musandamensis Lees.

The greater part of this limestone formation must be of Jurassic age.

Throughout the central part of Oman a thick series of shales, thin bedded sandstones, breccia limestones, and red and green radiolarites is developed (the Hawasina series). Lavas are interbedded with the upper horizons and the group is associated with great igneous intrusions (the Semail Igneous series), mostly of basic character, serpentine, etc., although gabbro, diorite, and even granite are present. Fossil evidence of the age of this series is lacking. The only specimen found could not be identified with certainty, but it has Upper Jurassic affinities, *Nerinea* cf. *punctata* Brown. The Hawasina series has a thickness of about 5000 ft.

5. *Triassic*—The Musandam limestone conformably overlies a group of Upper Triassic, probably Carnic, yellow sandstones, shales and thin limestones. The following forms have been determined by Dr. Lees :—

Ostrea blanfordi Lees.
Myophoria omanica Diener.
Myophoria gigantea Lees.
Chlamys (*Æquipecten*) *clignetti* Boehm.
Lima (*Plagiostoma*) *subvaloniense* Krumbeck
Lima subcamaunica Krumbeck.

4. *Hatat Phyllites*—A group of sericite, calc and chlorite phyllites of unknown age. They appear in a tectonic window in the Saih Hatat Plain. They may represent metamorphosed Mesozoic or Paleozoic sediments and lavas, indeed they bear a certain resemblance to the phyllites of the vicinity of Hamadan in Persia, which are in part of Paleozoic (probably lower Carboniferous) age.

3. *Permian*—Rocks of Permian age underlie the Triassic without angular unconformity. In Ruus al Jibal a massive dark-coloured limestone contains many sections of large brachiopods, among which *Richthofenia* was recognized. In Wadi Adi behind Muscat the limestone yielded :—

Productus indicus Waag.
P. gratiosus Waag.
Athyris royssii Lev.
Streptorhynchus cf. *pelargonatus* Schl.
Retzia remota Eichw., etc.

These limestones may be correlated with the Indian Middle Productus limestone. Andesitic lava flows are interbedded with the series.

In the central part of Oman, inland from Khabura, some sheared masses of Permian limestone have been found of an entirely different type. They are white or cream-coloured limestones with abundant corals, crinoids and bryozoa. One limestone yielded *Neoschwagerina globosa* Yabe.

2. *Pre-Permian*—There are two series of pre-Permian rocks of unknown age in Oman. On the S.W. side of

Saih Hatat Plain the Permian unconformably overlies a thick quartzite formation; on the N.E. side there are a number of limestone and shale groups with interbedded lavas of pre-Permian age. They contain organic remains but no recognizable fossils have been found.

1. *Pre-Cambrian*—At Kalhat, ancient granite gneiss outcrops, similar in every respect to the basement rocks of the foreland at Murbat. Kalhat lies within the Oman orogenetic zone, and the relationship of this mass of old rocks is not clear. Perhaps it is a sheared mass, appearing as it does in an area of strongly folded Hawasina series.

Tectonics

The structure of the Oman ranges is very complicated and great areas of the country are quite unknown geologically. In general, however, it is a zone of intense movement, great thrust sheets have been formed, and in the case of Saih Hatat, sediments, probably Mesozoic or Paleozoic, have been metamorphosed to sericite phyllites, etc. The zone of basic intrusive rocks, associated with a shale-sandstone series with a great development of red radiolarites (the Hawasina series), occupies a great areal extent. The basic rocks and the radiolarites may be traced through Oman to Masirah Island and Ras Madhraka; there they disappear into the Arabian Sea striking in a S. 35 W. direction. Farther along the southern coast in the Kuria Muria Islands and at Murbat, the old crystalline rocks appear and the country has a gently folded foreland character.

Upper Cretaceous rocks, notably Maastrichtian, are transgressive on the older strongly folded complex. Sedimentation continued through the Eocene and locally into the Miocene, and subsequently a gentle folding and a general elevation of the ranges took place. The summit of Jebel Akhdar, 9900 ft. high, is probably composed of Eocene limestone. The present form of the Oman mountain arc is therefore of late Kainozoic age, but these movements are of very subsidiary importance compared to those of the earlier pre-Gosau phase. Locally some violent disturbances have taken place, but in general the movement is one of gentle folding and elevation of the ranges.

The general form of the Oman ranges suggests that they are part of a continuous outer arc of the Zagros system, rejoining the mainland structures at Cape Monze, W. of Karachi. This, however, only applies to the late Kainozoic movement. The earlier pre-Gosau structures appear to have followed an independent course, passing from Masirah Island southward into the Arabian Sea. There is no indication that these structures have ever been connected with the Sind ranges. The age of folding and the lithology and general nature of the tectonics of the two systems bear no comparison, but, on the other hand, the distance between the two series is great (500 miles).

To the N. a number of the characteristic Oman rocks reappear in Persia. In the Zindon Nappe, N.E. of Bandar Abbas, there is a shale series with a great development of red and green radiolarites associated with basic intrusive rocks, very similar lithologically to the Hawasina series. They have also a great areal extent between Kirman and Niriz where they seem to have been involved in Cretaceous movements, although to what extent is not known. It seems that the pre-Gosau geosynclinal zone of S. Persia divided, and one branch passed southward through Oman. Subsequently the connection between the two countries broke down and the Upper Cretaceous-Kainozoic geosyncline crossed the older structures, following an independent trend. The later Pliocene movement maintained this direction in general, but the influence of the older Oman structures acting as a buttress is evident in the marked kink of the strike between Bandar Abbas and Jask.

PART VI. CONCLUSION

In the above pages we have given the results of our geological observations. We have seen that the Iranian ranges form a typical orogen ; in the S.W. is the Arabian foreland ; then comes a very broad folded (and in the N.E. parts sheared) zone, which varies in width from 100 to 200 miles ; then comes the Napped Zone which is followed by the Median Mass or Zwischengebirge. The hinder part of the Napped Zone

in the environs of Hamadan and Isfahan, passes over gently into the Median Mass. The S.W. Iranian ranges, in their behaviour towards their foreland, Arabia, can be compared with the N. Carpathians, with the Alps, or with the Dinarids in the Balkan Peninsula. They are different from the southern Alps.

In discussing the movements, we have to point out that in the Iranian ranges, as in other places, a shifting of the folding movements took place. The successive movements of different zones can be studied only if one makes sections across the whole width of the Iranian ranges, and they cannot be cleared up by studying only some of the zones of deposition.

It is now generally accepted that during the geological history of the Earth there have been periods of relative quiescence during which epeirogenetic movements took place, alternating with orogenetic periods of much shorter duration. The epeirogenetic movements result in the formation of geanticlines and geosynclines and the orogenetic movements in anticlines and synclines.

All these movements have a world-wide extension. Of course the strength of the movements is not everywhere the same, and also it may happen that the orogenetic movements correspond in certain places to movements of epeirogenetic character. These movements have been called by Stille, synorogenetic movements (" syn " in the sense of " at the same time as ").

These synorogenetic movements are of shorter duration than true epeirogenetic movements. On the other hand, in epeirogenetic periods, movements of orogenetic character can take place in rocks which are very mobile. These are the synepeirogenetic movements (for example, movements of salt, or of Lower Fars).

Stille, on the basis of an extensive study, has worked out the canon of the orogenetic movements. He has shown well the world-wide extension of these movements in certain periods. This canon may be changed, but it gives a safe guide in studying the geological history in different countries.

From the fact that the folding shifted from zone to zone, it follows that certain movements can only be recognized in

certain zones. In other zones these movements may be reflected only in a change in the character of the sediments, or in a very slight folding, in the formation of "plissements précurseurs."

Much has to be done to clear up the above-mentioned movements, but it seems to us certain that the older movements in the zone of the nappes and in the more strongly folded zones were also expressed in the more gently folded zone where the main folding is of Wallachian age, but where most of the anticlines were already expressed to some extent before the Wallachian movements.

In Cambrian times a shallow sea extended across the Zagros and we find its deposits extending to the N. of Kirman. No Silurian is known in the Zagros Mountains proper; the presence of Devonian is doubtful; Lower Carboniferous is not known, but only Permo-Carboniferous. None of these Paleozoics is metamorphosed; somewhat metamorphosed Paleozoics (with *Orionastræa*), occur only in the most north-easterly napped zone.

The Trias and Jurassic are known near Kermanshah and may be represented in Dashti and to the S.E. thereof, as they occur, according to Dr. Lees, in the Oman ranges.[1]

In the Median Mass the same Paleozoics occur and Devonian also, which is transgressive. This incomplete Paleozoic series overlies old rocks. Trias is apparently present in one place; then perhaps comes Rhætic and then Lias; younger Jurassic beds are not known.[2] The Paleozoic and Jurassic sea was in the N. Along the N.E. parts of the Zagros there may have been a trough along which Paleozoics came in, which may have been somewhat folded in Hercynian times, but the folding was not very strong. The absence of the Silurian may indicate Caledonian movements, but they too must only have been of epeirogenetic character. Then, at the end of the Jurassic, a great change occurs. A big trough was formed—the Iranian geosyncline—in which accumulated sediments ranging from Lower Cretaceous up to Pliocene. At the same time the Cretaceous transgressed over the Paleozoic folds and the Median Mass. It is an outstanding

[1] See postscript, no. 9, p. 214. [2] See footnote, p. 138.

feature that in this Iranian geosyncline the strong pre-Gosau movements of the Alps are missing.

In Dashti the gypsum beds below a Cenomanian or Albian fauna seem to indicate slight movement. Stronger movements are expressed in the Upper Cretaceous, as proved by the thick Maastrichtian sandstones and conglomerates composed of detritus from the green and radiolarite zones. They are particularly well developed from Khurramabad north-westward to Sulaimani and Agra. Locally the Upper Cretaceous is transgressive in the napped zone. The conglomerates in the Kuh-i-Ginao and Kushk Kuh may be taken as expressions of Laramid movements. The Laki transgression is very well marked in Dashti and S.E. thereof. In the N. at Dohuk and in the Bazian Pass near Sulaimani, conglomerates and sandstones, above Alveolina and Nummulitic limestones, show the neighbourhood of a shore. Then in Dashti, conglomerates and breccias with gastropods occur above *Nummulites gizehensis* beds from S. Dashti to Gavbandi, and from Kuh-i-Gavbust to Anguru. These conglomerates and breccias apparently express the Pyrenean movements, but they may be partly due to the fact that the Laramid movements had caused anticlines further E. and that the Eocene beds containing conglomerates were deposited near a shore. In Iraq and Kurdistan, Eocene limestones overlap the Eocene conglomerates, and in the Kushk Kuh pebbly Oligocene follows thick deep-water beds of the Eocene. In the Kuh-i-Siah and in the Kuh-i-Ginao, the Oligocene is unconformable over the Eocene and is missing in S. Dashti and to the S.E. thereof to beyond Gavbandi. Savian movements are well expressed W. of the Euphrates and the Miocene is transgressive over Eocene and Oligocene. Pebble-beds containing Oligocene limestone occur near the base of the Miocene in the Qara Chauq Dagh. In the Jebel Atshan the Lower Miocene overlaps Eocene. In the Kushk Kuh and in the Kuh-i-Siah the Lower Miocene is transgressive or discordant and in S. Dashti and to the S.E. thereof to beyond Gavbandi, the Miocene is transgressive on Eocene. Lower Fars is in several places separated by conglomerates from the Lower Miocene limestones. But the main movements occurred in Pliocene times ; the Bakhtiaris, which contain

Hipparion, are strongly folded, and in the Zindon range Eocene Flysch is thrust over Bakhtiaris; this fact is very important.

The Oman range shows a different behaviour. A Radiolarite Nappe occurs here also. It is evident, however, that the Radiolarite Nappe of the Zindon range forms a garland with the Radiolarite Nappe N.W. of Chahbar, where the Metamorphic Nappe of the Zindon range is also present. It is most probable that this garland existed in Cretaceous times and that it was separated from the Oman range by a region with the character of a more stable part, in fact a sort of Median Mass. If so, the Oman range is a virgation. The radiolarites of Masirah Island may perhaps belong to a third outer garland. The picture may have been the same as in the case of the West Anatolian and Syrian ranges: large garlands with different rocks and history.[1] This view differs somewhat from that of Dr. G. M. Lees, as expressed in the chapter on Oman. The depths of the northern part of the Arabian Sea are not abyssal and would not contradict our view. In any case further investigation is needed.

In the Median Mass old rocks are overlain by the Paleozoics described above, and some Mesozoics; next is an igneous series overlain by Cretaceous which is transgressive; then a break between Cretaceous and Eocene, and Paleogene volcanic activity; then transgressive Aquitanian with *Lepidocyclina elephantina* Mun.-Chalm.; then a strong filling up of big subsiding synclines, with deposits up to 15,000 ft. thick; then a late Pliocene folding and then faulting around the synclines. In connection with the late Pliocene movements, the whole area has been elevated to form a plateau 3000 to 5000 ft. above sea-level.

Argand has given a brilliant synthesis of Eurasia, and basing on inter-continental and intra-continental drift, he gives us the following picture:—

Asia consists of the following old nuclei welded together: the Siberian massif, the Sinian massif, the S.W. Chinese massif, and the Tarim block or Serindia.[2]

[1] W. Penck, *Die tektonischen Grundzüge West-Kleinasiens* (1918).
[2] If it is a nucleus.

The Paleozoic ranges have been formed between and around these nuclei, but, as we have seen, the Median Mass of Central Persia is also partly pre-Cambrian and overlain by unmetamorphosed Cambrian deposits.

The Alpine cycle begins, according to Argand, in the Permian or in the Triassic, and for him the history of Eurasia is, since the Cambrian, a duel between Eurasia and Gondwanaland.

Between Eurasia and Africa there has been a strong compressive movement. The N. mass has a relative southward drift; the southern or Gondwana continent had a relative northward drift. These two drifts closed the great geosyncline of the Tethys. In late Pliocene times an expansion started which caused the old Tethys rift to re-open. This rift cut off a part of Africa; the N. chains of the Alps, with the detached part of Africa, moved further N.; the Mediterranean rift widened and deflected the Apennine chain from an E. to W. to a S.S.E. to N.N.W. trend and thus caused the great final overthrust of the Alps and the Carpathians.

During the Alpine movements would have been formed, in Oligocene time, the Gulf of Mexico and the Caribbean Sea.

The study of the Alps has shown that strong folding went on in Mesozoic times.

Argand claims that Africa was pushing forward at the very time when we know that the Iranian geosyncline was formed; and at the time when the main Pliocene folding of the Iranian ranges took place the Red Sea was already in existence as a region of stretching, so that we would only have Arabia left to push against the S.W. Iranian ranges. As we have seen, the Zagros behaves towards Arabia like the Alps towards their Foreland. If the Alps have been pushed northwards over their Foreland, so should the Zagros have been pushed southwards towards Arabia.

Staub says[1] that at the end of an orogenesis there sets in automatically in the deeper sub-crustal masses a counter-movement, which causes the flow of the heavy magmas of the former geosyncline towards the Poles. The "Polifugal" force has reached its target—the joining of two contin-

[1] R. Staub, *Der Bewegungsmechanismus der Erde* (1928).

ents by a more or less equatorial mountain-system—and is now practically reduced to zero; therefore, the above magmatic flow will cause a drag on the continents, as a consequence of the friction on the base of the rigid solid blocks, and this pull will try to drive back the continents towards the Poles. Hence they will be strongly stretched at certain places and finally break along certain zones. The formation of geosynclines is caused, according to him, by these factors.

Argand has a similar idea. But during the formation of the Iranian geosyncline, Africa should have been pushing northwards, at least in Cretaceous times; so that, if the reasoning of Staub and Argand be correct, we should have either the twisting of Africa away from the Median Mass of Persia, or we should have a northward movement of the Median Mass of Persia and the adjacent parts of Asia; and for these movements we have no proof.

Another consideration is involved. Kober[1] has pointed out the significance of the Median Mass, and Staub in his splendid synthesis, *Der Bewegungsmechanismus der Erde*, has shown clearly many of the principal features of the Median Mass. For him, the Median Mass is a more stable part of an old orogen which is simply surrounded by the ranges of the younger orogen. He attributes to these blocks a rather passive behaviour. Argand makes these Median Masses a part of the squeezed-out orogen, as the following profiles show (Pl. XIX).

The Pannonian (Hungarian) basin and Central Persia are two cases of a typical Median Mass. In the Pannonian basin every irregularity is filled up by Miocene and younger deposits which are folded into very gentle brachy-anticlines and brachy-synclines. Mr. Pavai Vajna has published a map of the principal trends of the Pannonian basin, which map is based on the results of the work which was inaugurated and conducted by de Böckh in Hungary. De Loczy, Senr.,[2] has pointed out that the Rhodope massif had continued into Hungary, and we find the Lias developed in a Grestener facies (coal-bearing) along a line which was the shore of a mass

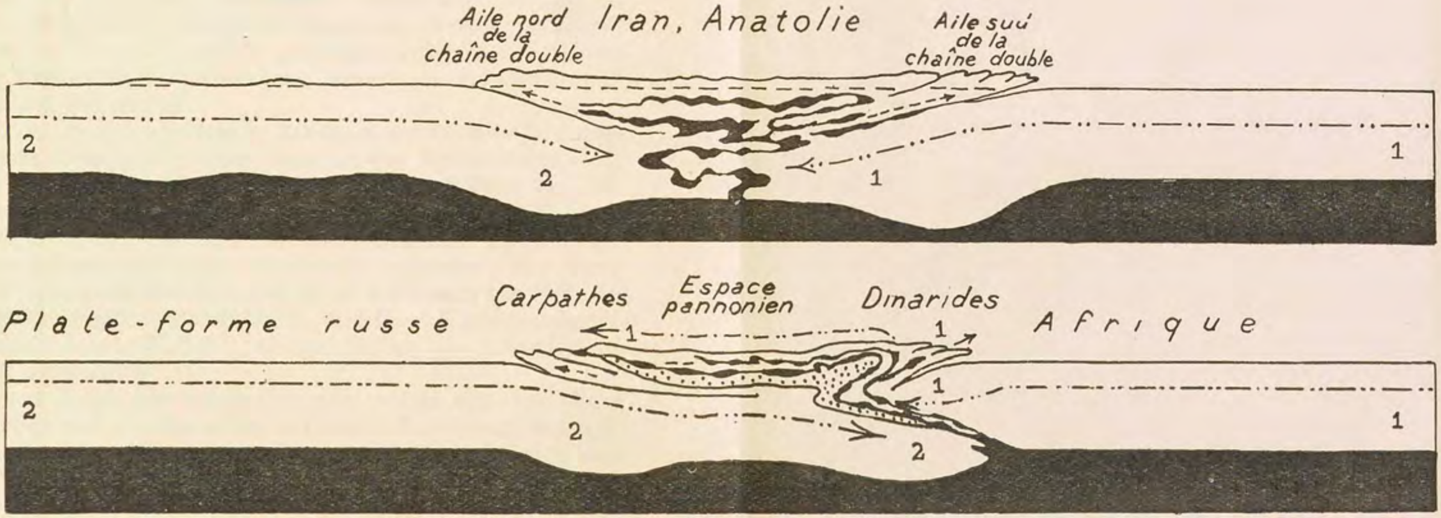
[1] L. Kober, *Der Bau der Erde* (1921); *Gestaltungsgeschichte der Erde* (1925).

[2] L. de Loczy, *Geologische Studien in westlichen Serbien* (1924).

which Peters and Mojsisovich have called the Oriental Dry-land. In the Middle Mountains, N. of Lake Balaton and near Budapest, there are broken-down folds of Mesozoic rocks. The Eocene is transgressive and came over a strongly eroded surface. During Kainozoic times the Pannonian basin was an area of subsidence, different parts of which were covered by the sea in different periods. It is very difficult to conceive how and why a subsidence should have taken place in the Median Mass when the Carpathian ranges were being pushed towards and over their foreland, if the Median Mass be the middle part of a big fold system which the rückland or back-land of Africa is pushing out. Moreover, the napping movements along the Carpathians are not all of the same age. In the W. Carpathians they were finished sooner than in the E. and S. Carpathians. In the S. Carpathians even the late Kainozoic beds are involved, whereas in the N. the Ostrauer Tegel is resting quietly above the northwards-pushed Nummulitic, and the orogen broke in, forming the Inter-Alpine basin of Vienna, while in the E. and S. Carpathians, napping movements were going on. Accordingly, the volcanic activity, the result of which is the "Inner Carpathian Volcanic Wreath," is older in its W. part and younger in the E.; a shifting of the volcanic activity took place. This fact is very difficult to explain on the hypothesis of a continuous northwards push. If the data published on the Taurus are correct, here too the movements stopped earlier in the Taurus than in the Iranian ranges.

The Iranian Median Mass is much bigger than the Hungarian Plain and is much more elevated. The Pannonian basin is partly lower, partly somewhat higher than the foreland. The Caribbean Sea is a flooded Median Mass. In keeping with its greater size, the anticlines and synclines are bigger in the Iranian Median Mass than in the Pannonian basin, but otherwise, the Pannonian basin, if more elevated and eroded, would show the same features as the Iranian Median Mass.

The tectonics of the Median Masses are not Alpinotype but Germanotype, and they show some likeness to forelands. Both can develop a great volcanic activity with lava-flows, but the character of the igneous rocks is not the same.



TWO PROFILES AFTER ARGAND, *TECTONIQUE DE L'ASIE*

1, 1, Gondwana; 2, 2, Eurasia. Black, Sima. White, Sal. Dotted, Tectonic Products from the Axial Zone of the Tethys

The Persian Median Mass has in parts been flooded with volcanic material. In the case of the Hungarian basin we know only the "volcanic wreath"; but the strongly magnetic behaviour of certain brachy-anticlines makes it probable that there is volcanic material present at depth.

According to the conception of Kober, parts of Mexico should be a Median Mass which is flooded with volcanic materials. De Böckh, F. D. S. Richardson, J. R. Bourchier, and A. H. Taitt have examined Guatemala. In the N. parts of this country wonderful nappes are present, all moved to the N. The S.W. and S. parts and adjoining territories are a Median Mass and here we have again lava-flows and volcanic agglomerates.

The shales and phyllites of the most north-easterly nappe in Persia pass gently over towards the Median Mass. It seems to us that the whole nappe is a big geanticline, the S.W. frontal part of which forms a *pli faillé*, while the N.E. flank slopes gently down towards the Median Mass. Then follow long anticlines with large intervening synclines; the steep side of these anticlines is in the W. area towards the N.E., in the Dasht-i-Kavir towards the S., and E. of Kirman towards the Dasht-i-Lut (E.N.E.), always facing the direction of greater subsidence.

Argand in his admirable synthesis, points out that along the meridian of the Kara Sea and the Gulf of Oman, through the basin of the Obi and the Turgai and through Turan and Iran, there was a depressed zone during the Alpine cycle, the forerunner of which existed already in Cambrian times. We know Lower Trias deposits at Kur near Julfa in Armenia, above the Permian; Krafft found the same beds in Bokhara. The Middle and Upper Trias are not known from here. In Afghanistan occur *Monotis salinaria* Schl. and *Daonella indica*. In Baluchistan *Monotis* and *Halorites* have been found, and the Norian form *Didymites*. No Trias has been found in the Zagros[1] ranges, or in the Iranian Highlands, except at Naiband, N. of Kirman. The Permian in the gorge of the Araxes near Julfa is separated by a discordance from the Carboniferous, and is overlain by concordant quartzite of

[1] See footnote, pp. 69, 85, 138.

the Lower Trias. Then we have Permian again in the first Paleozoic napped zone.

In Turkistan Permian is known at Bokhara, and Tournaisian and Visean near the Araxes. In the first Paleozoic nappe, in the Kalian Kuh, limestones with *Fusulinella sphærica* Abich 1858 and *F. lenticularis* Douv. are probably Uralian. Near the Araxes the Devonian is concordant with the Carboniferous. The Devonian transgression came from the N.W., the Silurian is missing, and the Cambrian stretches in a shore-near facies from the Persian Gulf to N.E. of Kirman. In Central Persia there seems to be no Silurian and no continuity between Devonian and Carboniferous. A Paleozoic shale facies is developed near Hamadan and in the most north-easterly nappe of the Zagros. All these facts point to the conclusion that a depression ran along the Zagros Mountains, whereas parts of the Median Mass along the meridian of the Gulf of Oman and the Kara Sea was generally elevated, though flooded at times, but then only temporarily. The Median Mass of the Iranian highland has existed since ancient times. Of course it has been folded like the pre-Cambrian nuclei of Asia ; but no Alpinotype tectonic is to be seen, and the profile (Fig. 24), after Messrs. R. C. Jennings and K. Washington Gray, shows distinctly a folding towards the E.N.E., *i.e.* towards the Dasht-i-Lut depression.

From the above it seems to us clear that the Median Mass has not merely a passive, but some active part, and the sinking down of these masses may also act as driving-power. We consider that our present knowledge should be summarized as follows: there are, as is well known, stable and unstable parts in the crust of the Earth. Some stable parts, especially the continental nuclei, preserved their stability over long periods. The stable parts are the forelands, and the less stable the Median Masses. These two units are either moving towards each other or away. If they are moving towards each other the unstable parts between them are formed into mountain-ranges. The cause of these differential movements has been much discussed. We cannot enter here into a detailed discussion of the different views, which are put forward and discussed in the works of Argand, Kober, Staub, Wegener, and others, and in the symposium

on the Continental Drift Theory. What we have pointed out in the present paper is, that although we are not against a certain drifting, this drifting is surely not so uniform as there is an inclination to believe. Different parts of the stable masses do not move at the same time and the direction of the movement changes. We think that, stimulating and useful as are the thoughts of Wegener, Argand, etc., we have much to learn before we can make a correct synthesis, but they have given a new impulse to our conception of mountain-building forces.

The explanation of the drift theory depends much on Isostasy, which is based partly on gravity measurements, partly on the interpretation of the observations of earthquake-waves. But are we entitled to draw from these measurements such far-reaching conclusions as we are inclined to do? The gravity measurements on which Isostasy is based were not made at closely-spaced stations. The only large area over which, to our knowledge, such a close network is available is the great Hungarian Plain. The results of measurements there throw doubt on conclusions from measurements made many miles apart. A comparison of the measurements made by Baron Eötvös and Dr. Pekar with those by R. von Sterneck show that selected areas of the oceans and continents should be surveyed in great detail before far-reaching conclusions be drawn. Even the measurements by Dr. Vening Meinesz published in the *Geographical Journal* for February, 1928, are certainly too far apart.

Another fact which should be remembered is that our geological knowledge is not sufficiently advanced to permit of a safe general synthesis.

Some of us had the opportunity of making more detailed studies in Colombia and working out a profile from La Guaira in Venezuela through Caracas and Villa de Cura to Ortiz. The results obtained are very different from the generally accepted ideas.

The Pre-Cretaceous Colombian Andes were formed by parts of Caledonian and Hercynian ranges, and the Paleozoics have a wide distribution.

In the Cordillera Central, near Puerto Berrio, we found

graptolite-shales of Ordovician age, and Dr. Gertrude Elles, who was so kind as to determine the collected *Didymograpti*, fixed the age of these beds as Arenig. R. A. Liddle[1] mentions Devonian rocks from the Sierra de Perija, and Stutzer[2] mentions from near Gachala, N.E. of Bogota, sandstones and limestones containing fossils which are most probably of Upper Carboniferous age. The limestones contain *Spirifer*, *Productus*, and crinoids, and the sandstones have *Cordaites*, *Neuropteris*, etc. Up to the Carboniferous, the Paleozoics seem to have a normal marine facies; then come red and greenish beds which have been called Jiron sandstones. In the Bucaramanga section this series is about 16,000 ft. thick, and in it four distinct groups can be observed. These beds are overlain by Cretaceous, the oldest recognized stage being Barremian. The red and green rocks are much like the Todos Santos beds of Guatemala. There, too, the latest marine Paleozoics are of Upper Carboniferous age; then folding occurred, and the red and green Todos Santos beds were deposited. The transgression of the Cretaceous seems to have been later in Guatemala than in Colombia, as we could not find anything older then Middle Cretaceous. The age of the red and green series cannot be determined exactly, but these beds are between the Upper Carboniferous and the Cretaceous and may represent Permian, Triassic, and Jurassic in Colombia, and the same formations with Lower Cretaceous in Guatemala. The salt-plugs in the neighbourhood of Bogota, which penetrate the marine Cretaceous beds, must be connected with these older beds. It is interesting that the Todos Santos beds of Guatemala contain gypsum near San Mateo Ixtatan and both gypsum and salt near Quetzal. We must here note that part of the Santa Rosa beds in Guatemala are equivalent to the Todos Santos, and appear in tectonic windows and pinched-in wedges from below overthrust Carboniferous.

In Colombia, towards the end of the Cretaceous, strong folding took place in the E. Cordillera, and between Mutiscua and Pamplona the crystalline rocks are pushed eastwards

[1] R. A. Liddle, *The Geology of Venezuela and Trinidad* (1927).

[2] O. Stutzer, "Beitr. z. Geol. d. Kolumbianischen Ost. Kordillere," *N.J. Min. B.-Bd.*, Vol. LVII, B. (1927), p. 314.

DIAGRAMMATIC PROFILE OF THE COUNTRY BETWEEN PUERTO SANTOS AND PAMPLONA.
DEPARTAMENTO DE SANTANDER DEL NORTE
COLOMBIA.

Constructed from observations by Prof: H de Bockh and F.D.S. Richardson
with additional observations between El Tambor & Puerto Santos.
by Messrs. J. Chapman Brown & H. K. Long.

Scale Horizontal & Vertical = 1:100,000.

HINTERLAND ZONE OF NAPPES.

over the Cretaceous (see Pl. XX). As far W. as Bucaramanga, Alpine tectonics are to be found. After the Laramid movements breaking down took place and strong erosion set in. To the S. of El Banco, where the Cordillera Central crosses the Magdalena, the Kainozoic beds are river and lake deposits which overlie the most diverse stages of the eroded Cretaceous. The older rocks all show an eastward movement, but no napping in post-Cretaceous times can be observed. The Cauca Valley is a ditch, and it is very difficult to find out what rocks are buried at depth. It seems that the Cordilleras Central and Occidental really formed one old Hercynian range, perhaps a gigantic geanticline, which shows a virgation towards the N., and that in the central part of it was formed a depression which later on developed into a rift-valley. It is very important that here pre-Cretaceous and post-Cretaceous igneous rocks appear. The presence of Cretaceous igneous rocks is doubtful, and if they are present it would mean a great difference between this area and the continuous Cretaceous sequence of the Magdalena valley and the region in front of the Cordillera Oriental, where no Cretaceous igneous rocks are known. The igneous rocks near Natagaima, which have been said to penetrate Cretaceous "Guaduas" beds, are older, and the "Guaduas" here are of pre-Cretaceous age. We have changed the whole stratigraphy of Colombia in essential points. The term "Guaduas," for instance, has been applied to pre-Cretaceous rocks and also to coal-bearing rocks at the top of the Cretaceous. In the gorge of the Lebrija, where it cuts through the La Paz range, the pebbles of this coal formation are contained in the La Paz sandstone, which is therefore younger than this "Guaduas," whereas the "Guaduas" beds of the type-locality of Guaduas are above the La Paz sandstone. We had to make this short diversion in discussing the Andes. It is, moreover, important that in the N. parts of the Rio Atrato basin no Cretaceous has been observed, and it seems that parts of the Cordillera Central and the W. Cordillera played already, at the time of the Laramid movements, the rôle of a Median Mass.

As we have said, after Laramid times breaking-down of the whole area on a large scale took place. The Cretaceous

deposits were strongly block-faulted and step-faulted; the Kainozoic beds, over 10,000 ft. thick, filled up the areas of subsidence and were folded. Then again intense breaking-down occurred, probably towards the end of the Pliocene, and volcanic activity set in. The Mesa Tuffs near Honda, which have been said to be horizontal, show zones of shattering. The Kainozoic beds of the Sinu Valley and Atrato basin are immensely block-faulted. We see here clearly a period of compression followed by a period of dilatation. Then comes again a period of compression, but in this period there are no more Alpine structures produced. The folding is Germanotype.

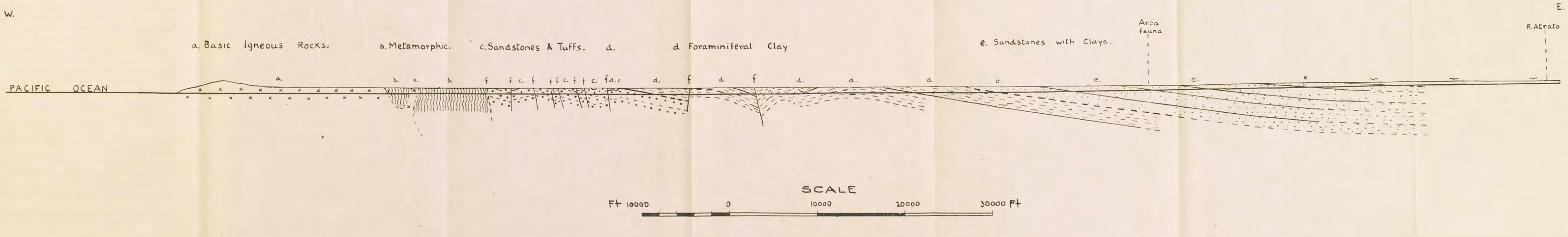
Messrs. Shaw, Hubbard, and Mitchell have examined the area W. of the Rio Atrato. The attached section (Pl. XXI) shows that basic igneous rocks and metamorphosed shales, of as yet undetermined age, are overlain by gently-dipping rocks, at the base of which there seem to be volcanic agglomerates and tuffs. These are overlain by foraminiferal marls and clays, and then follows a thick sandstone group. The series is faulted and no evidence is found to support a westward drift of the South American continent. Bosworth's map of N.W. Peru, assuming its correctness, is equally negative.

The facts observed show the expression of a certain pulsation of the Earth. Many studies deal with the possible causes of pulsation or alternating phases of expansion and contraction; [1] the signs of it are there. But it is not in the Alps that these questions could be solved; it is in the areas where the Kainozoic movements have not been strong that one can study an orogen which has, so to speak, stopped at an earlier stage. The Colombian Andes show the same stage that Gignoux shows for the Swiss Alps at the end of Jurassic times. The Cordillera Oriental is really a complex of geanticlines forming *plis-faillés* on a gigantic scale, and it seems to us that a closer examination of the napped zone of Persia will reveal a similar structure.

The attached profile (Pl. XXII), through Caracas and Villa de Cura to Ortiz, which was worked out by de Böckh, F. D. S.

[1] F. Nölke, *Geotektonische Hypothesen* (1924); Joly, *The Surface History of the Earth* (1925); W. de Sitter, "On the Rotation of the Earth and Astronomical Time," *Nature* (1928).

PROFILE FROM THE RIO ATRATO ACROSS THE WESTERN CORDILLERA OF COLOMBIA TO THE PACIFIC OCEAN IN LATITUDE 6°40′ N. (AFTER MESSRS G. M. SHAW AND G.H. HUBBARD)



Richardson, and in its S. parts by J. V. Harrison in more detail, shows an orogen moved towards Archi-Guiana. It is not a northwards pushed orogen, but southwards, as Kober has postulated. The Caribbean Sea is a Median Mass, as Staub pointed out, but there is no northward napping movement in the Venezuelan Andes.

Another point in general synthesis of the Earth is the much discussed question of the permanence of the Pacific Basin. Again Isostasy, earthquake-waves and the geologic structure of the Andes are cited in the discussion of this question.

From the above short description of the Colombian Andes it is evident that their history is very different from the history of the Andes in Peru. In the neighbourhood of Santa Elena in Ecuador, a S.W. to N.E. strike can be observed, and it appears as though the Cretaceous and the much discussed cherts (which may be an equivalent of the chert group of the Cretaceous of Colombia) strike out into the Pacific. Gregory has pointed out that the Peruvian Andes strike out into the Pacific in the surroundings of Callao, and the same strike can be observed near Paita. We must mention that the chert group of the Cretaceous, which occurs below the Guadaloupe sandstones and grits, has a great extension in Colombia.

The following question arises: are we entitled to draw the Andes as a continuous chain round South America? Are these ranges really homologous? Suess remarked on the difference, and reading Dr. J. A. Douglas' [1] papers on Peru, one is inclined to have certain doubts as to the justification for the drawing of the Andes in this manner. In any case much work is necessary to settle the outstanding difficulties.

Van der Gracht thinks that during the Laramid revolution the magma behind the Cordilleran bulge began to work towards the equator (Taylor's Drift), particularly after solidification of the Sima was in progress, and the American frontal bulge had become grounded, blocking an outlet of the possibly tidal Sima current to the west, and that this may have caused the curious subsequent expansive drifting apart in the equatorial belt, re-opening the present Mediterranean. But

[1] J. A. Douglas, "Geological Sections through the Andes of Peru and Bolivia," I, II, III, *Quart. Journ. Geol. Soc.* (1917, 1920, 1921).

why then, may we ask, have the rifts in Colombia a N.N.E. or nearly N. to S. strike, and why should the collapsed Kainozoic anticlines in northern Colombia have a north-easterly trend, and towards the Gulf of Uraba a northerly and north-westerly trend? We cannot enter here into a discussion of these problems. What we wish to do is to point out that not only in Persia but also in other parts of the world, there are many geological questions to be cleared up, and that we have to study carefully the history of the different parts of the orogens before a well-founded explanation can be given. The same conclusion was come to by the recent symposium on the Continental Drift Theory.

One point in Argand's synthesis will however stand unchanged, namely the conclusion that most, if not all, of the crustal movements are due to changes in the inner part of the Earth, and that the crust is adapting itself to these changes.

In the above pages we have not dealt with the Elburz. In several places we have pointed out differences between the Elburz and the regions dealt with, but we have not enough data for their discussion. Kober and others consider the Elburz as a part of the Alpine branch. Stahl's profiles across the Elburz do not allow of such interpretation. But the researches by Golubiatnikoff show that at the northern foot of the Elburz the Kainozoic is overfolded to the N., while northerly movements seem to prevail along the road from Kazvin to Rasht. Here also further work must be done before definite statements can be made.

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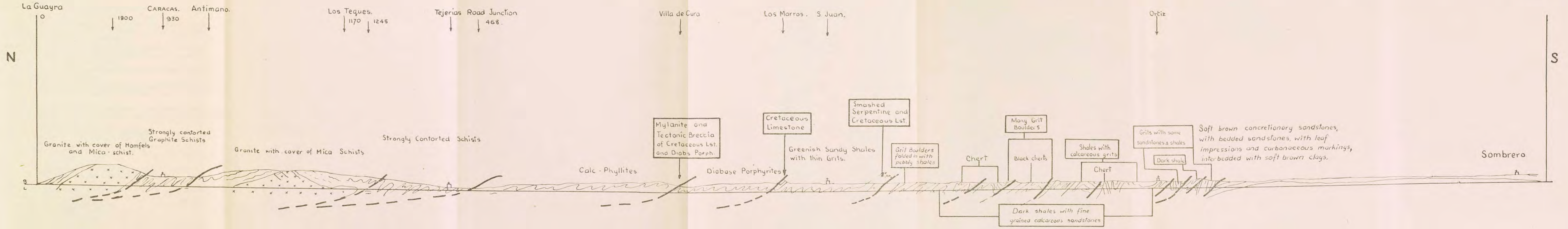

— DIAGRAMMATIC PROFILE OF THE COUNTRY BETWEEN LA GUAYRA AND SOMBRERO. —
— VENEZUELA. —

— SCALE. —

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TECTONIC SKETCH-MAP OF THE IRANIAN RANGES AND PARTS OF CENTRAL PERSIA
DIRECTIONS OF MOVEMENT.
ANTICLINAL TRENDS.
REGIONAL PITCH OF SOME ANTICLINES IN THE AUTOCHTHONOUS FOLDED AND SHEARED ZONE
TRENDS PROBABLY REFLECTING PALAEOZOIC MOVEMENTS.
NAPPE-FRONTS, WHERE OBSERVED.
NAPPE-FRONTS, WHERE INTERPOLATED.
I FLYSCH-NAPPE.
II NAPPE WITH NORMAL PALAEOZOICS.
III RADIOLARITE-NAPPE IN PERSIA.
IIIa SERPENTINES, RADIOLARITES, ETC. IN OMAN.
R RADIOLARITES.
S SERPENTINES ETC.
IV CRETACEOUS LIMESTONE NAPPE.
V NAPPES WITH METAMORPHOSED PALAEOZOICS.
APPROXIMATE SOUTH-WESTERN AND SOUTHERN BOUNDARY OF MEDIAN MASS.
AREAS OF SUBSIDENCE WITHIN MEDIAN MASS.
SALT PLUGS IN S.W. PERSIA (C = WITH CAMBRIAN FOSSILS).
SALT PLUGS IN THE MEDIAN MASS (MIOCENE).
XX PALAEOZOIC OUTCROPS. (C = CAMBRIAN, D = DEVONIAN, P = CARBONIFEROUS, PERMO-CARBONIFEROUS, PERMIAN.)
ARMENIA
CASPIAN SEA
ELBURZ MTS.
DASHT-I-KAVIR
DASHT-I-LUT
PERSIAN GULF
MAKRAN
OMAN
LURISTAN
PUSHT-I-KUH
TEHERAN
BAGHDAD
BASRA
KUWAIT
BUSHIRE
KERMANSHAH
HAMADAN
YEZD
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MOSUL
KIRKUK
AHWAZ
BAHREIN
MUSCAT
CHAHBAR
LAKE
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CHAPTER IV

THE TECTONIC FEATURES OF THE EAST FERGHANA AND ALAI RANGE

By Prof. D. I. Mushketov, Director of the Geological Commission of the Soviet Republics.

East Ferghana is a district in eastern Turkestan beside the Chinese frontier and E. of Samarkand and Kokand. The great valley of Ferghana is bordered on three sides by low hills, the " Adyrs," of Upper Cretaceous and Kainozoic rocks, with occasional bosses of Paleozoic. This valley is bounded to the S. by an Alpine range, the Kichik Alai, a branch of the Alai Range. The rocks of the area include a long succession ranging from the Middle Cambrian to the Middle Carboniferous and including Silurian and a full representation of the Devonian. The sea withdrew in the Upper Carboniferous, and continental sediments were then laid down and continued through the Permian and Trias to the Lower Jurassic. The country was again reached by the sea in the Cenomanian and the deposition of marine beds began then and lasted till the Oligocene. The last deposits belong to the Pleistocene and include abundant loess.

The tectonic problems regarding East Ferghana are exceedingly complicated and interesting ; they have been elaborated by me step by step and explained in a series of papers as the evidence was collected. It will be convenient first to divide the region described into a number of tectonic subregions and types ; then to summarize the types ; and finally consider which of the theoretical foundations and hypotheses are most successful.

The tectonic subregions, as will be shown in the sequel,

correspond closely with the orographic regions, as is natural in a country that has been affected by such recent intense earth-movements. According to the current theories of the structure of Central Asia, East Ferghana is tectonically a region of collision and struggle for space intermediate between the Tian Shan and the Pamir, while part of it has remained passive under the supposed influence of the hypothetical mass of Kashgaria-Serindia. More strictly defined, East Ferghana is a region originally created by the Tian Shan folding and by the Alpine-Pamirian geosynclinal folding. The Tian Shan folding advanced from the N. and swept westward about the mass of Serindia, which according to Argand is the western part of the Central-Asiatic segment and has its edge between the meridians of 73° and 74° E. The Alpine-Pamirian geosynclinal folding advanced from the S. The upper portion of the ancient structure was first over-folded from the N. and subsequently affected by movements in the opposite direction which fractured and crumpled it; after those movements it was liable to be over-ridden by sheets thrust on to it from the S. According to this scheme of earth-movements there was a southward thrust-motion in the northern portion of the region, which retained its original "Tian Shan" character, and also along the northern border of Serindia; but the thrust was northward in the southern part of the region, and this overthrust upon the southern and western borders of Serindia increases southward, and is accompanied by extensive thrust-planes and fractures which strike E. and W. Moreover, the edge of the segment, which, as already remarked, crosses the region between the meridians of 73° and 74° E., corresponds with the farthest northern projection of the Indian mass (the mass of Gondwanaland), which is thought to have been pushed from the S. upon Central Asia; the northern border of the Indian mass is clearly outlined by the northern border of the alluvial plain of the Indus and the bold arc of the Himalaya. Twelve years ago I showed how the deforming influence of that projection of Gondwanaland produced the plaited arcs of the Pamir, with their sharp northward bend between the 73rd and 74th meridians; and, though the influence vanished gradually to the N., it caused the curvature of the southern Tian Shan ranges, as well as

in particular the very sharp crumpling exhibited in the "Ferghanian horizontal flexure."

That scheme can now be amplified and slightly modified; but all its essential features may be retained, as it has not yet been substantially refuted by anybody, and nothing else has been proposed in its stead. The chief new idea, as I have repeatedly advanced in contradiction of the views of I. Mushketov, E. Suess, and V. N. Weber, is the denial of the existence of two intersecting foldings of different directions and dates. Those authors adopted a Paleozoic "Alaian" folding with a N.E. strike, and a Kainozoic "Ferghanian" folding with a N.W. strike; the mutually perpendicular ranges that skirt East Ferghana—*viz.* the Alai and Chotkal ranges with a N.E. trend and the Ferghana range with a N.W. trend, have been represented as the direct expression of these two foldings (see Fig. 3, p. 11).

All the confusion in the tectonic views has been caused by the obscure and contradictory location of the Ferghana range, which was then known in but few places. Moreover such stupendous knee-bent flexures of the whole of a great folded complex were not then recognized. Finally, the compound brachitectonics of the domes and troughs, within which sudden changes of strike at right angles necessarily occur, and the fringed folding of the borders of the Ferghana basin and its cliffs, with their deep bays and straits cutting far into the ancient mountain ranges, appeared obscure and were misleading when observed only in rapid route-surveys of the region. It is interesting to observe that all the geologists who have contributed to the interpretation of this region have been right from their own viewpoints. Thus von Richthofen was right in distinguishing the Tian Shan from the Pamir, in claiming the more intimate relation of the Tian Shan to the Alai, and in his denomination of the N.W. striking ranges as "Schleppenkettung" (drag chains) and the S.W. striking ranges as "Ruckstaukettung" (back-pressure chains). The antithesis of these ranges was explained as virgations by I. Mushketov and E. Suess, and they were therein at least partly correct. I. Mushketov was also right in his recognition of a S. to N. movement in the southern arcs of Turkestan, though he did not state it with sufficient definiteness and

sharpness; and he was also indirectly right in speaking of a struggle between two perpendicular directions of uplift, as in the Gulcha and Tar corner and other localities. This struggle is now obvious, and on a larger scale than was apparent to him; but *the cause was* not *the intersection of two directions*, but *the passage from the one to the other*. This passage is accompanied by distortion, by radial fracturing of the adjacent exterior arc due to tension, by crumpling of the internal part over which the exterior part is thrust, by longitudinal fracturing and overthrusting with imbricate displacements of certain parts of the limb in respect to others, by strong vertical bulging in the points of maximum distortion, and by pitching of the axes of young folds away from such bulgings; moreover, on the limbs of the folds pertaining to the principal plane, secondary folds, which strike perpendicularly to the primary folds and have their axis pitching away from the major arc, must arise at the turning points of the flexures.

We now pass to a brief account of the tectonic characters of two of the principal regions, which are grouped by us as follows:—

I. The Alai range and its forelands—the southern fringe of the Ferghana.
II. The Ferghanian-connecting flexure.
III. The Baubashata ridge—the northern fringe of the Ferghana.
IV. The Ferghanian depression.

I. *The Alai range* is tectonically characterized by an almost strictly E. to W. trend, and by a primary overturning of the Paleozoic folds to the S. with their subsequent deformation in the opposite direction. The later northward overfolding is expressed by the refolding of the folds and especially by the appearance of longitudinal fractures which are accompanied by imbricate thrusts of the southern parts upon the northern; this process is very vigorous in the S., beyond the limits of the areas yet explored (40° N.), but it becomes gradually less marked to the north and vanishes completely at the parallel of Osh, where it is replaced by a reverse movement. The same may be seen in the profile section by V. N. Weber of a more western part of the Alai range.

II. *The Ferghanian Flexure* (and allied elements) occupies

nearly the eastern half of the district and represents, in my view, a connecting link between the Tian Shan and the Alai ranges. This link is shaped like a Latin S, that is having two turns at right or at greater angles, and a median part striking N.W. Contrary to my former view, however, I do not conceive that flexure as having a continuous strike through all its constituent tectonic ranges; it is a connected series of domes and troughs, or is a brachitectonic structure developed on a very large scale.

The detailed structure of the Paleozoic domes is not yet quite clear; but the above-stated interpretation of the Ferghanian flexure is supported by all the data concerning the Paleozoic rocks summarized in my tectonic map, and also by the existence of a central outcrop of the Silurian System bordered by Devonian and Carboniferous. The dome of Cha-kan-tash, whose centre lies in the inaccessible district of Kyzyl-agyn–Aldan-Kul–Sauk-tur, is more clearly defined; it represents the northern ending of one of the large complex anticlinals of the Alai range, and it is exposed by the meridional valley of the Kok-su; the head portion of that river has cut only as far as the dome. Its nature as one of the elements of the Alai chain is revealed, as it is a median anticline flanked on both sides by lateral anticlines, other complications being, however, probable.

The turns in the Ferghanian flexure are especially prominent in Dagdul, along the northern border of the Cha-kan-tash and thence towards Kara-tuma and Palvan-tash, along the Tar Valley, which strives to follow this turn.

Proceeding from the exterior of the dome towards its centre we meet more and more ancient series; but this impression is at first obscured along the northern outskirts by the beds having been overturned northward, which is clearly seen at the mouth of the Chon-Kazyk River. The overturning was accompanied by recumbent folds and by thrusting, which is chiefly from the S.; the recumbent folds are seen on the frontier in the Dungreme range and the overthrusts of the Paleozoic upon the Cretaceous series are seen on the right slope of the Ak-bogus valley, on the Oi-Kain, and the Iaman valley. The influence of the southern pressure of the Paleozoic mass is none the less revealed, in the absence of direct

overthrusts, by the northward overturning of the Mesozoic folds. The Mesozoic cover which surrounds the Paleozoic domes and projects from both sides between the domes in a meridional direction along the river divide between the Tar and Kara-Kuldja; and this cover displays everywhere the thrust-effect of the Paleozoic mass, as in the overthrusting from the S.E. along Kara-bel of one part of the Jurassic series upon another part. By studying the region of the Paleozoic domes we, moreover, become acquainted with the ancient erosion plane by which these domes were destroyed, when a Triassic-Jurassic bay deposited its sediments at a uniform level which is now 7880 ft. above sea-level.

Amidst the highly crumpled and complicated tectonic regions to the E. of the Cha-kan-tash and Kyzyl-agyn dome, in the eastern corner of the district lies a peculiarly undisturbed simple trough; it is elliptical in outline, and extends for 25 miles E. and W. This trough appears to present a knot of rest due to the interference of the different foldings. The trough may be termed "the red trough of Alaiku," for its floor is occupied by red Lower Cretaceous sandstones; in the centre of the trough one remnant of Upper Cretaceous marls is displayed in the Chichir-ganak heights.

The syncline of Alabuga exhibits essentially the same peculiarities of structure as the other tectonic elements; for it shows the abrupt, highly upturned younger rocks where they are in contact with the ancient frame. The dip of the young rocks is always away from the older rocks; and while on the whole the dip is centripetal from the steep narrow anticlinal core, yet the dip is markedly steeper in the underturned south-eastern limb; and, in addition to the general indications of southward thrusting, the folds are here clearly overturned and a N. to S. overthrust has pushed the Paleozoic upon the coal-bearing Jurassic beds. The similar tendency of the Tian Shan to push southwards has been remarked for a number of localities in North Kashgaria by German geologists, as well as by myself in a long cross-section of the southern Tian Shan that was drawn from Aksai to Kashgar, along the valleys of the North and South Terek rivers. As the Tian-Shan in Kashgaria met with a passive resisting mass, the Tian Shan simply over-rode it; whereas

in the Pamir it was opposed by an active resistance, or counter-movement, which produced a series of complex deformations, crumplings, flexures and their functions—the brachitectonic structures—and an overthrusting from the south was succeeded, beyond a certain latitude, by a northern overthrusting.

The same conclusion is supported by observations on the jointing of the crystalline rocks.

In conclusion mention may be made of an exceedingly important, but formerly inadequately appreciated conclusion of J. M. Mushketov, regarding the structure of the Alai range; he considered that range as being isoclinal, with a general southerly dip which may however be south-easterly in some places along the flexures. This structure of the Alai range is supported by our observations throughout its whole length.

The characteristic tectonic features of the explored region, which is to some extent unique, may be summarized as follows:—

1. "Envelopment domes," with a structure like that of an onion, consist of cores or islets of the folded Paleozoic mass that were left by denudation during continental conditions and by erosion during the advance of the Cretaceous sea; these cores were later enveloped by Mesozoic and Kainozoic deposits. The Kainozoic beds have been partly removed from the surface of the Paleozoic islets and remnants have been very capriciously crumpled between the cores. The crumpling was always functional, and dependent on the disposition of the ancient masses; for the beds are steeply inclined near the contacts with the older rocks, and the dips are gentler at some distance away, while the crumpled periclinal cover shows radial fracturing (faults, heaves, etc., as in Kochkarata, etc.). The false, dependent, passive brachitectonics of these "envelopment domes" is therefore dependent on the pressure from without, while the domes were passive.

2. True independent brachitectonics are present both in the Paleozoic on a large scale in the connecting flexure and in the Mesozoic and Kainozoic series; they are also present on a minor scale and more capriciously developed at the re-entrants of the Paleozoic frame.

3. Troughs of crumpling and subsidence with peripheral

faults and occasional anticlinal eczematous bulgings (Central Ferghana, Alabuga, Alaiku), and sometimes salt-domes.

4. Some special cases, in which Mesozoic and Kainozoic rocks underlie the Paleozoic, require different explanations in each case: either (*a*) by an active thrusting of the Paleozoic upon the Mesozoic (or in some cases of older upon younger Paleozoic) attaining in the southern ranges (Trans-alai range) and the Pamir dimensions of true thrust-planes; or (*b*) by the overturning of great Mesozoic flexures in their contacts with the Paleozoic, which has there been passive.

5. An apparent false unconformity occurs where horizontal beds lie upon vertical beds belonging to the same system, as in the thick Jurassic sandstone-shale series, the Suyak facies; this arrangement is explained by a peculiar type of angular folds in which some beds remain for a considerable length absolutely flat; these straight parts are connected by parts that have been tilted to angles of between 20 and 40 degrees. The series appears not crumpled or undulating, but broken, like sheets of hard material.

6. Complicated step-folds (or " Eskaladierende Falten," as on Gorumdy) are typical of the Jurassic of the Ferghana range.

7. Finally, the turns of the great Ferghanian flexure are characterized on their external parts by transverse radial folds in which the axes pitch towards the exterior, and by cross-faults, or dip-faults which have a north-western strike and are exhibited in the re-entrants of the southern branch.

Passing now to the question of the possible cause of such disturbances as those observable in East Ferghana, I see but one possibility—the contraction theory—which I hold exclusively. Theoretical discussions of this question would be misplaced here. But the character of the troughs of Ferghana, Alaiku, and Alabuga and the gravity observations both show that the troughs are members of a large simply folded complex formed by horizontal forces. The fundamental process of contraction acted at earlier and later times and in different ways—including orogenic and epeirogenic movements; and both movements took place repeatedly and alternately. The following phases of the orogenic movements are firmly established in Ferghana :—

1. The Variscan, at the end of the Lower Carboniferous; the first Tian Shan phase.

2. The Upper Paleozoic, Permian; the second Tian Shan phase.

3. The post-Oligocene Pamir phase.

The following epeirogenic movements may be traced by stratigraphical breaks, transgressions, and regressions that show no angular disconformities:—

1. An early Paleozoic submergence which caused the transgression of the Cambrian Sea over the whole of the Turanian basin; to this movement we apply the term "Turanian."

2. A pre-Cenomanian submergence which caused the entry of the Cenomanian Sea into East Ferghana through Bukhara (Bokhara) and the Alai; we therefore term this movement the "Bukharian."

3. An Upper Senonian-Laramian emergence which caused a temporary shoaling of the sea (as shown by the absence of the Danian), and for which the evidence is clear in the Suzak section: this we call the "Suzak" movement.

4. A Middle Eocene submergence which caused the entrance of the sea into East Ferghana, through a strait near Khodshent; we therefore call it the "Khodshentian."

5. An Upper Oligocene emergence—the last, or "Ferghanian" epeirogenic movement; it excluded the sea from East Ferghana and started the accumulation of thick conglomerates which were later disturbed by the orogenic movements of the Pamir.

CHAPTER V

RECENT WORK BY THE GEOLOGICAL SURVEY OF INDIA ON THE NORTH-WEST HIMALAYA

By W. D. West, Geological Survey of India.

During the past four years the Geological Survey of India have started to re-survey the Simla Hills. H. B. Medlicott first investigated this area, and he was followed by Oldham and others, though no serious work has been done for more than thirty years.

It has now been shown that the sequence of rocks found in the type area of Solon does not hold good at Simla and elsewhere. At Solon the Simla slates and Blaini beds are overlain by the Infra-Krol and Krol; but at Simla they are overlain by rocks showing a higher grade of metamorphism, named the Jutogh series. Detailed mapping has shown that three large overthrusts pass through the district, of which the uppermost brings on the metamorphic Jutogh rocks at Simla. They form an isolated capping to the Simla ridge, and are here comparatively thin. But further S.E., around the Chor mountain, a much greater thickness of these beds is found, and detailed examination of them has revealed that they are disposed in several flat recumbent folds of great amplitude.

The Jutogh beds show mainly a moderate grade of metamorphism. But in the vicinity of the Chor granite there is a slight but definite increase in the grade of metamorphism, so that certain well-defined zones can be made out. The mapping of these zones shows that the metamorphism is definitely posterior to the recumbent folding. The latter, therefore, has no connection with the much later overthrusting, which is almost certainly post-Eocene. The metamorphism and recumbent folding are thought to be Archæan in age.

Two other series have been separated, the Chail and Jaunsar series. They show a low grade of metamorphism, and are taken to be post-Jutogh and pre-Simla series in age. They are frequently thrust over one another and over the Simla series and Blaini.

For various reasons the Geological Survey of India now wish to revert to Oldham's correlation of the Blaini with the Talchir beds of the Peninsular, instead of giving them a Purana age as suggested by Holland.

There is no doubt that the movements which took place in post-Kainozoic times in this part of the Himalaya had a south-westerly direction of movement, resulting in the piling up of older rocks on younger by overthrusting. Whether there were movements on the northern slopes of the Himalaya in a contrary direction is not known, by reason of the lack of geological information. But in such areas as have been investigated, *e.g.* Spiti and Kashmir, the folding all seems to be of a comparatively simple type.[1]

[1] The following table indicates positions assigned to the formations referred to in this chapter. *Cf.* also p. 18.

?	Krol Series. Infra-Krol beds.
Upper Carboniferous.	Blaini beds, with glacial boulder bed.
Lower Paleozoic.	Simla Series.
Purana System.	Jaunsar Series. Chail Series.
Dharwar System.	Jutogh Series.

CHAPTER VI

THE STRUCTURAL EVOLUTION OF EASTERN ASIA

By Prof. G. B. Barbour, Yenching University, Peking.

This paper traces in a generalized way the tectonic growth of that third of the Asiatic continent which lies north and east of the Himalaya, excluding Japan and the other members of the chain of island arcs.

Anyone seeking to gain a coherent picture of Asiatic structure finds himself at once under a great debt to the illustrious father [1] of a previous speaker. In fact such a study becomes virtually an analysis of how far the classic conclusions of Eduard Suess have to be extended or modified as the result of observations made since *Das Antlitz der Erde* appeared.

It would clearly be out of the question to give, in the twenty minutes allotted to me, details of the evidence available to-day for analysing the structure of so large an area as the entire north-eastern third of Asia! I shall be content with offering in somewhat diagrammatic form an outline of the main stages in the development of that structure as I understand it. In so doing I shall draw freely on the researches of Berkey, Grabau, Obruchev, Teilhard de Chardin, Willis, and Wong, of Suess himself and of many others, but shall avoid obscuring the main picture by references or quotations, even on issues which may seem open to debate.[2]

In listening to Dr. Suess' paper my attention was caught by the use of one term which bears directly on the question in hand. He referred to the trough-like depression along the

[1] Dr. Eduard Suess, University of Vienna.

[2] A few of the more valuable sources of information are listed at the end of the paper.

front of a folded mountain range as a "fore-deep." Till more is known of the processes of mountain building, we must distinguish between those chains which make the volcano crowded festoons fronting the ocean deeps, and the intracontinental mountain ranges. Grabau is right in drawing a clear distinction between a true *fore-deep* (Fig. 9)—such as those round the Pacific basin where a deep submarine trough

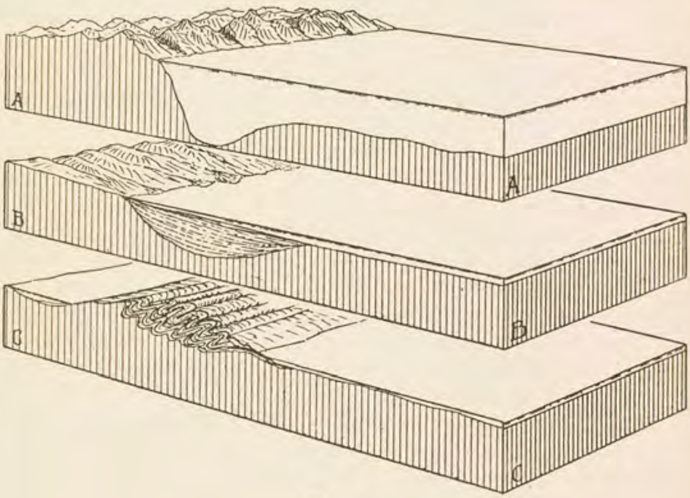

FIG. 9.

A.—Typical Foredeep.
B.—Geosyncline, showing shallow water character.
C.—Folded range on site of geosyncline; new geosyncline developing in old land parallel to fold-axis.

has formed at the margin of a negative (subsiding) block of the earth's crust where it abuts a rising positive continental element—and the *geosynclinal trough*. The latter seems invariably to form within the limits of a continental mass, is at all times essentially a shallow feature (so that in some cases its upper surface never lies below sea level), and continues to sink *pari passu* with the infilling of sediment so that the shallow-water character of the latter is maintained even when

the trough-bottom has sunk to a depth of hundreds, if not thousands, of feet (Fig. 9B). As a further feature we may recall that, in the case of most of the older geosynclines, sinking did not continue indefinitely, but eventually the movement was abruptly reversed, the zone of subsidence being forced vigorously up and its sediments folded to form the new mountain system, often to the accompaniment of igneous activity. In a number of cases a new zone of subsidence subsequently formed parallel to the recently folded geosyncline (Fig. 9C).

The crucial points in the history of Asia lie in such times when the steady process of erosion and deposit were rudely interrupted by these crustal disturbances.

The present relief of the continent is clearly of comparatively modern date. There has been ample time for all pre-Kainozoic surface inequalities to be worn down; to-day motor cars can drive at fifty miles an hour over the exposed roots of levelled Mesozoic ranges in Mongolia. At the same time, the dissection due to recent uplift has exposed structural controls that were established at much earlier dates; thus, although the immediate cause of many mountain ranges lies within the limits of the Kainozoic Era, the ultimate tectonic control is often far more ancient.

Of the most ancient recognizable mountain systems, as judged from the trends of foliation in the early pre-Cambrian gneisses of eastern Asia, little is known. Observations are still too scattered to be co-ordinated with certainty. In many places however (as for instance in the East Sayan Mountains, around Lake Baikal and in north-eastern China) there is a definite general agreement between the strike of the pre-Cambrian foliation and the axes of Paleozoic and Mesozoic folding. More specifically, recent observations corroborate the general structural trends indicated by heavy lines in Ruedeman's pre-Cambrian map (see References). The latter, however, does not show the meridional strike developed locally where the two dominating trends converge south-west of Lake Baikal.

Of the Paleozoic and younger ranges more can be said. As the simplest means of combining the data in a form that may be easily grasped I shall make use of paleogeographic

maps, asking you to bear in mind that they are at best only a convenient means of recording and interpreting scattered observations, that no greater accuracy can be hoped for than those observations possess—a very uncertain quantity where observers are at variance as to fact or interpretation !—and that even to-day data are still so scanty for much of the continent that these approximations themselves will need to be modified as new facts become available.

The maps used are redrawn from those of Dr. A. W. Grabau with only slight modifications. Dr. Grabau's reconstructions of paleogeography are founded primarily on a careful study of the distribution and faunal content of marine sediments—the traces of the older mountain systems as here represented are additions to his originals. In places the areas shown as marine must be only the minimum extent of the seas, erosion having removed the traces of their extreme limits. Similarly the finding of two distinct contemporary faunas in nearly adjoining districts may have led to the drawing of a land isthmus between two basins, whereas the actual barrier was a submarine slope, a temperature gradient or some other condition which prevented a mingling of types.

But with all their defects such reconstructions of ancient geographical relationships become valuable aids to interpretation of structures if used with discretion.

The stages represented in the maps I have chosen are those critical in the growth of the continental structure. The first (Fig. 10), shows roughly the presumed distribution of land and water in Upper Silurian times. It embodies, amongst others, the following facts : (1) the area of the Irkutsk basin was covered by Lower Paleozoic marine deposits yielding boreal types of fossils which must have had free access through a channel to the N. almost till the close of the Silurian Period ; (2) the basin must have had a source of supply for sediment, and as deposits of that age do not extend beyond the margin of the basin as mapped,[1] it was presumably surrounded, in part at least, by land ; (3) faunas showing close relationship with European and Himalayan types occur as far E. as South

[1] The dotted line indicates a possible extension to the East where presumed Silurian types are recorded from the region of Obruchev's newly-discovered Cherski range.

China, but the connection with the Indian Ocean, so characteristic of some stages of the early Paleozoic, had been broken. It may be added that, by alternately opening and closing the marine alleys connecting the south-China Mediterranean with the Indian Ocean and the East Siberian Gulf respectively, this Upper Silurian paleogeography represents a land-sea

FIG. 10.—EASTERN ASIA IN UPPER SILURIAN TIMES. (After GRABAU, modified)

relationship which had persisted throughout Cambrian, Ordovician, and Silurian times, and which may, therefore, be taken as typical of early Paleozoic conditions.

Early in the Devonian Period the Middle Paleozoic (Caledonian) movement caused an abrupt permanent change. The margin of the Irkutsk depression was folded by stresses directed towards the centre of the basin giving rise to the ranges

shown in Fig. 11. This established two trend-lines recognized by Suess,—the Sayan trend (N.W. to S.E.) and the Baikal trend (N.E. to S.W.)—which were of persistent effect. Tet-

FIG. 11.—THE SAYAN (S) AND BAIKAL (B) TRENDS ESTABLISHED BY THE CALEDONIAN FOLDING OF THE MARGIN OF THE FORMER IRKUTSK BASIN.

yaev is the only observer who questions the dating of these folds; on the basis of the Mesozoic deposits in the East Sayan range, he believes the Sayan trend is much younger than the Baikal trend: the other Russian geologists, however,

discredit this interpretation, and support Suess. Obruchev even assigns the folding of part of the eastern Altai to the same Caledonian readjustment—a conclusion supported by the observations of Berkey and Morris in Mongolia.

Fig. 12.—Middle Devonian Marine Channels. (After Grabau, modified.)

For simplicity I have compressed into this one diagram (Fig. 11) connected events which probably were spread over a period of time. For instance, the folded margin of the Irkutsk basin may well have been partially reduced by erosion

before the new subsidence occurred along its western margin. With the formation of this folded margin the Irkutsk basin was converted into the Paleozoic platform of Angaraland and has remained so ever since.

Thus far newer evidence serves to corroborate Suess. But, as has been pointed out by others, in his study of the later range-foldings, Suess, largely owing to the absence of data, did not clearly recognize the distinctness of successive independent movements. Some of these details are now available.

By Middle Devonian times (Fig. 12) the Tomsk geosyncline (T) with its boreal fauna has extended south to join a similar Mediterranean across Mongolia (M), together forming an arc roughly following the outer margin of the Irkutsk basin.

On the map, I have indicated by belts the position of the already reduced Caledonian folds of the Primitive Nucleus. In each succeeding stage a similar convention is used to show the " traces " of the pre-existing ranges even though these may have long ceased to appear as surface features.

At the same time marine waters had again found access to South China along the Himalayan geosyncline (H), while a connecting water-way followed the line of the Tian Shan with an important subsidiary arm north of Tibet along the axis of the Kuen Lun geosyncline (K). Later this Kuen Lun trough extended as the Nan Shan geosyncline (N) round the north-eastern edge of the Tibetan block, becoming an alternative channel of access to south-western China during the opening and closing of the Himalayan passage.

The Hercynian folding at the close of the Paleozoic was in many ways the critical one for east Central Asia. The area of the crust vigorously affected seems to have been much larger than before. Not only was the zone adjacent to the basin of Irkutsk creased up along the lines of the Tomsk and Mongolian geosynclines, but the Tian Shan, Western Altai, Kuen Lun, Nan Shan, and Tsinlin ranges came into existence, while the Urals rose to the N.W. Fig. 13 shows the position of these ranges (indicated by initials), relative to the trace of the basin of Irkutsk (*B* marking Lake Baikal), together with the re-distribution of marine waters early in the Triassic Period.

The naming of folding movements of this orogeny and the

mountain chains to which it gave rise is in a thoroughly unsatisfactory condition as there seems to be no general agreement as to the use of the terms Hercynian, Altaid, Variscan, Appalachian or late Paleozoic.

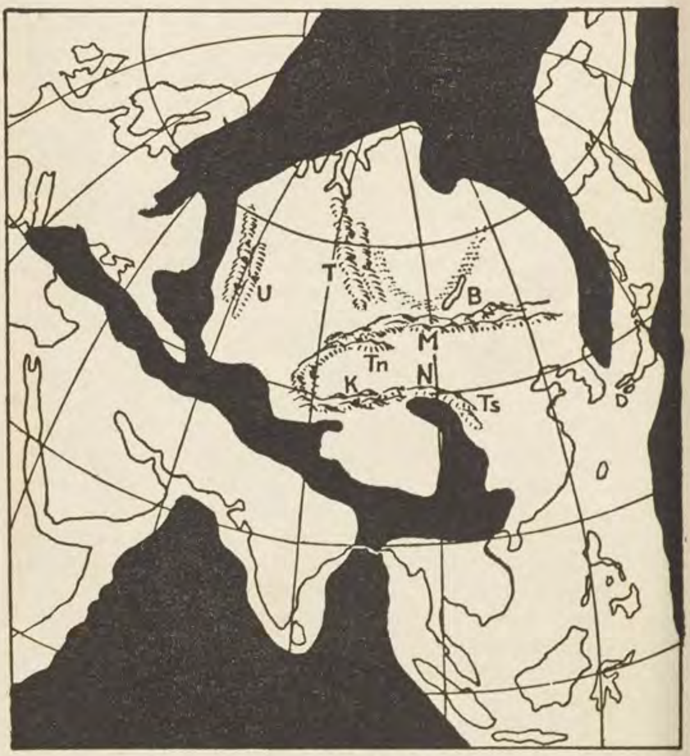

FIG. 13.—THE YOUNG MOUNTAIN RANGES AND WATERWAYS OF EASTERN ASIA IN EARLY MESOZOIC TIMES. Compare with Fig. 12. (After GRABAU, modified.)

In point of fact as far as Central Asia is concerned this orogeny is really a group of movements extending over much of two periods. The bulk of the Altaid group of chains of Suess belong to this Hercynian revolution. In Turkestan

Mushketov distinguishes two distinct maxima of disturbance —a first Tian Shan phase after the Lower Carboniferous, and a second Tian Shan phase late in the Permian. Obruchev makes a similar two-fold division of the Hercynian in

FIG. 14.—THE MIDDLE MESOZOIC FOLDED MOUNTAINS AND THEIR RELATION TO THE EARLIER SYSTEMS AND TO THE DISTRIBUTION OF SEAS. (After GRABAU, modified.)

Siberia, though his dating of the maxima differs slightly from Mushketov's.

The importance of the Hercynian movement lay in the fact that not only was it far-reaching in effect but it also so welded

together the block of East Central Asia that Mesozoic compressive strains accomplished relatively little folding in the heart of the continent.

The general effect of the Jura-Cretaceous disturbance is shown in the next figure (Fig. 14). In the interior this ends the yielding to compressive stresses. The erosion surface which bevelled the warped and buckled pre-Cretaceous strata marks the great break between the old and the new. In Mongolia, for instance, rocks below this horizon are well indurated, tilted and often metamorphosed; the younger formations are poorly consolidated warp-basin sands and gravels, or superficial lavas, neither of which have suffered severer deformation than that due to block-faulting or to the up-arching or further sagging of the bed-rock floor. The Cathaysian (C), Yenshan (Y) and Verkhoyansk (V) ranges were forced up at this time.

Finally, the Middle Kainozoic (and subsequent) adjustment produced the relief from which the present day topography has evolved.

Fig. 15 is again frankly a composite, embodying events which extended over more than one period. While the distribution of marine waters as shown is approximately that of Upper Miocene times, on the scale adopted no attempt can be made to distinguish the *folded ranges* of the Himalayan revolution from the *eroded arches* or *block-mountains* due to Kainozoic movements of uplift which continued long after the close of the Miocene Period and which in some cases have not ceased yet. For the third of Asia which lies to the north-east of the Himalayan group of folds, the intra-continental movement is almost solely of the warp or block-fault type. The welding process—which as far as the interior is concerned had been completed in the Mesozoic Era—was clinched by the throwing up of marginal folds on the Pacific border. The Cretaceous formations of Anadyr, Sikhota Alin and Sakhalin are found bent back along the old Hercynian trend athwart or oblique to the line of the Mongolian and Verkhoyansk geosynclines. The zone of folding encircles the Corea-China block, swinging up through the Nanling range and probably connecting with the south-eastern offshoots of the Himalayan group.

The structure of the Verkhoyansk-Kolyma mountain mass I do not profess to understand. The data available are scanty and inconclusive and the issue is not clarified by the

FIG. 15.—THE KAINOZOIC MOUNTAIN SYSTEMS OF EASTERN ASIA. (After GRABAU, modified.)

Note.—In many places where block-faulting follows earlier fold-trends the traces of the latter only are shown.

geological statement accompanying Sergei Obruchev's announcement of the newly-discovered Cherski range lying within the Verkhoyansk–Kolymsk–Anadyr arc. The Kainozoic movement which gave the area its present relief was

evidently only of the block-fault type combined with warping, any folded structure being of more ancient date. The latter appears to follow the trend of the arc. W. A. Obruchev says

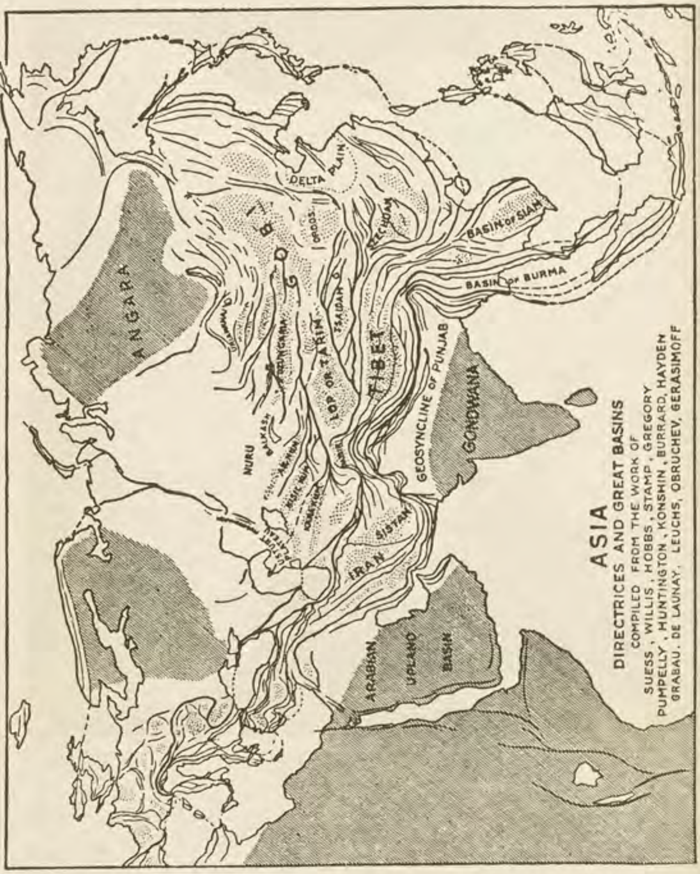

FIG. 16.

the Verkhoyansk geosyncline may have been wiped out in the Paleozoic Era, though he inclines to place the folding of both it and the Kolyma chain in the late Triassic ; the latter date is more consistent with the general tectonic history.

Passing finally to the extreme outposts of the continent, there is the problem of the late upheavals along the arcs of the island festoons. But upon this I shall not touch since it falls within the scope of another contribution to this discussion.

Suess seems to have thought of the creasing of the crust as due to the pressure extended by the southward advance of the nuclear mass, that is to say by roughly radial forces directed outwards from Irkutsk. Willis and, more recently, Hobbs have emphasized the fact that the actual direction of movement was inwards to the heart of the continent, as if due to stresses acting landwards from the Pacific and Indian Ocean basins. The same idea applied to the parallel case of the Laurentian shield is found in the epoch-making letter written by Logan to Barrande in 1860, quoted by the President of this Section.[1] "The resistance offered by the buttress of gneiss," he wrote, "would not only limit the main disturbance, but it would probably also guide or modify, in some degree, the whole series of parallel corrugations, and thus act as one of the causes giving a direction to the great Appalachian chain of mountains."

It is important to see how far the findings of the Central Asiatic Expedition to Mongolia bear out in detail the idea that the ancient nucleus has acted as a rigid promontory, against which successive creases of the crust were moulded, leading to the establishment of dominant trends of the fold axes in different regions. I reproduce the map compiled by Berkey and Morris showing the "Leitlinien" of Asia.[2]

In Mongolia a sharp lithological contrast exists between the folded elements of the pre-Cretaceous hard-rock floor and the gently warped basins filled with poorly consolidated younger sediments.

Berkey and Morris analyse the trends of four distinct types of structural line:

1. The fold-axes of the pre-Cretaceous rock floor,
2. The fracture lines of the Kainozoic fault-blocks,

[1] Mr. E. B. Bailey, Geological Survey of Scotland.

[2] The inner arcs of the Verkhoyansk-Anadyr region are additions made on the basis of data given by Sergei Obruchev, *Geog. Journ.*, Vol. LXX (1927), p. 464.

3. The major axes of the warped and faulted inter-mountain basins, and
4. The direction of elongation of the lenticular warp-depressions within these basins.

Of these structural types those in the hardrock floor are of first importance. They fall into two groups—(i) those with a general N.E. to S.W. direction including the Khingan trend recognized by von Richthofen in the East, and the Baikal trend of Suess which holds for most of Transbaikalia, and (ii) those striking E. to W., *viz.* the Altai trend for the Tian Shan-Tann-ola region, and Kuen Lun trend for the Richthofen, Nan Shan, and Tsinlin. The effect of the N.W. Sayan trend, which dominates for a short distance W. of Irkutsk, does not extend to the S.

In the pre-Cambrian and Paleozoic rock-basement of Mongolia the Altai trend dominates, except near Urga, where, as might be anticipated, the Baikal trend comes into play.

As to the tectonic character of the present ranges of Mongolia, they are essentially either dissected upwarped peneplanes (as in the case of the Khanghai-Kentai group and the old ranges of the warped provinces) or eroded arches or fault-blocks (as in the case of the Baikal-Yablonoi, and eastern Altai groups, the latter being in echelon owing to the fact that the faulting is oblique to the older structural strike). In summing up Berkey and Morris conclude: "Granting local divergences there remains a fair agreement between the old and new trends for five mountain-making revolutions . . . (implying) an orderly constancy of control."

In the main, for those regions of China, Mongolia, and south-eastern Siberia for which evidence is available, this general consistency between the older and younger "Leitlinien" appears to hold, divergence from earlier trends being most marked in the case of the later tensional faults. A sharp difference exists as a rule between the grades of dynamic and regional metamorphism affecting rocks above and below the major unconformities respectively—especially in the case of the Upper pre-Cambrian and Mesozoic breaks. But with certain localized exceptions there is usually no marked change in the trend of fold-axes of the type observed, for instance,

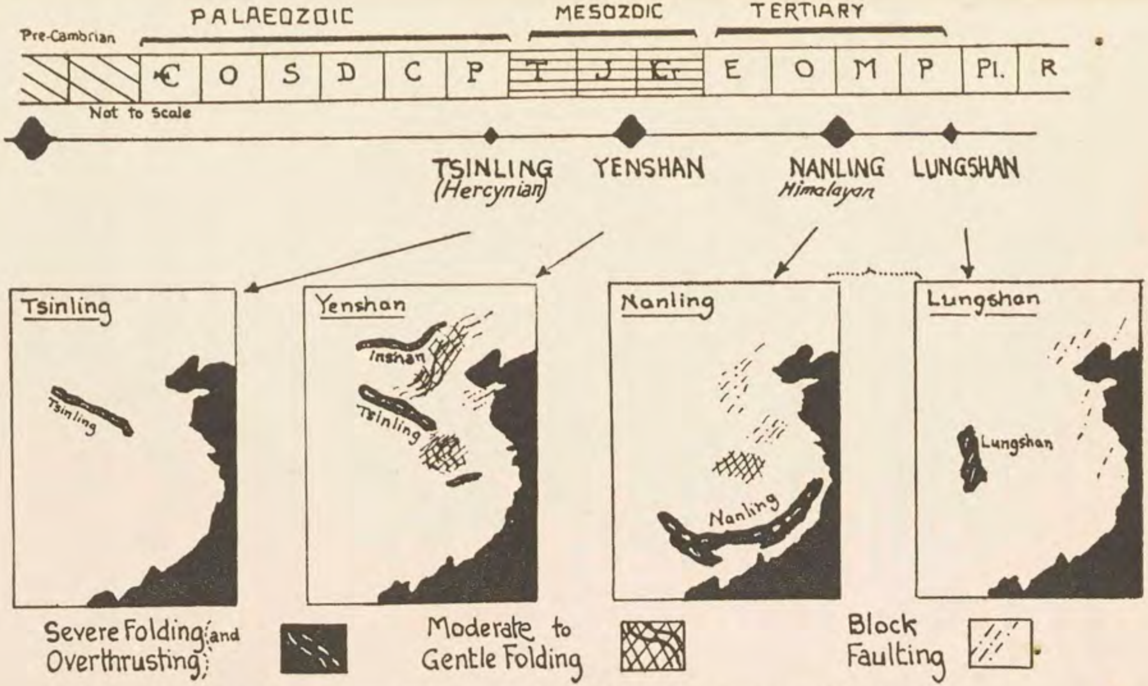

FIG. 17.—AREAS AFFECTED BY MAIN MOUNTAIN-BUILDING MOVEMENTS.

in Fenno-Scandia, a criterion which of itself could serve to distinguish " plis de fond " from " plis de couverture."

Turning finally to China as an area sufficiently distant from the Primitive Nucleus to be clear of any " short-range " influence, we find a history clearly in accord with that of the great interior. The four maps in Fig. 17 show in simplified way the areas affected by (1) folding of Alpine type, (2) gentle folding, and (3) faulting at each of the four main post-Cambrian diastrophic epochs. In general the zones of folding show the same tendency to shift outward towards the Pacific during the later movements.

The Hercynian movement was still busied with the interior of the continent, so that its effect (perhaps a little delayed) was restricted to the Tsinlin mountains.[1] The importance of the Yenshan Mesozoic revolution is clearly emphasized. Since then all the ground not in the immediate control of the Himalayan fold-system and its extensions to the S. and S.E. was spared from compressional movements.

But the welding process is not yet at an end. At the moment Asia is at an inter-orogenic stage in its evolution. Enough time has elapsed since the Himalayan revolution for erosion to have produced a surface of mature relief. The land stands high enough for geosynclines to be free of marine waters and hence less obvious. But the subsidence of the Indo-gangetic plain and the Yellow River delta indicate belts of geosynclinal sinking well within the continental area, which doubtless mark the position of ranges of the future.

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[1] Though the last stages of the Tsinlin movement are referred to by Wong as post-Permian, there is sufficient uncertainty as to the exact date of the youngest beds involved to warrant its being regarded as essentially part of the Hercynian disturbance.

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CHAPTER VII

OROGENIC EVOLUTION IN THE GOBI REGION OF CENTRAL ASIA

By Prof. BERKEY, Columbia University, New York.

THIS paper is based on personal observations made during two seasons as Geologist for the Central Asiatic Expeditions of the American Museum of Natural History, New York. On some five thousand miles of traverse, constant attention was given to the geologic structure, in a determined effort to discover whatever system might be disclosed in the succession of geologic events with special reference to deformation.

Relief features of mountainous character of the present day in the Gobi region are readily interpreted. They are arranged on simple lines, and the deformation responsible for them is equally simple, but there is evidence of older ranges of much more complex structure and history in the ancient rock floor beneath the so-called Later Sediments of these interior basins.

It should be recalled that the structural framework of the Gobi region falls easily into two great groups of strata. The lower portion of the geologic column, up to the base of the Cretaceous, is of comparatively complicated structure, and that part of the geologic history of the region was closed by a long period of erosion which developed widespread peneplanation. All formations preceding that time belong to the so-called Oldrock Floor.

On top of this basement, deposits were accumulated which constitute the so-called Later Sediments of the region. The principal elements of the standard column from the lowest Cretaceous to the present are represented, although they are not equally well represented, for at many places over large areas the Oldrock floor is entirely free from accumulation of any kind. The maximum thickness of the Later

Sediments in the districts thus far examined in detail by the Central Asiatic Expeditions is considerably over 5000 ft., although the average thickness is not more than a few hundred feet.

Interpretation of the structural features of the Oldrock floor leads to the conclusion that there are at least five sets of structure recording orogenic movement, each accompanied by volcanism. Each set has a character of its own sufficiently definite and sufficiently constant and widespread, and sufficiently different from the others, to warrant comparison for possible meaning.

I. The first set of structures of orogenic significance is strictly ancient pre-Cambrian in age. It is characterized by thorough metamorphism, with recrystallization of such sediments and other types of rock as existed at that time. The result was a series of schists, crystalline limestones, and schistose quartzites that were folded and otherwise intensely deformed. At the same time they were invaded by injections from igneous sources which modified greatly the composition and increased the structural variety of the original rock formations. Volcanism must have been of great importance in the mountain development and in the earth movements that were accountable for the mountains of that time. Some of the rocks became half-igneous by reason of these additions. At no subsequent time have igneous activities affected the rock formations of the region in such manner, although igneous rocks of much later age and apparently of even greater areal extent and prominence were observed.

II. Subsequent to this time, apparently at the close of the pre-Paleozoic Era, perhaps in the early Paleozoic, there was mountain folding of equally extensive character that threw all the formations developed upon the older pre-Cambrian floor into folds, some of which are comparatively open and regular, and some of which, especially those involving weaker series of formations, now form close, isoclinal and complicated structures. The great Mongolian batholith of granite was developed beneath this folded structure probably at the same time, and may have had much to do with the deformation itself and its character. But *it accomplished comparatively little in modification of the rocks themselves*, for there

is almost no intimate injection or complex penetration of the older strata chargeable against that time. Whether or not there was orogenic movement of any consequence in the Gobi region between this one and the earliest pre-Cambrian is somewhat uncertain, but if there was an additional step of that kind it had much the same character and effect, only less pronounced. This may be regarded as the period of great mountain folds. Volcanism took the form of great batholithic development beneath the crust, with many off-shoots penetrating the roof, but without the intimate injection of older rocks that characterized the earlier orogenic period.

III. At the end of Paleozoic time additional mountain folding took place. All of the Paleozoic strata are closely folded. But they are not so completely transformed by metamorphism and are in general little affected internally by igneous injection or invasion. There was volcanism, however, on a large scale, represented by intrusions of porphyries, outflows of lavas and accumulations of pyroclastics. The rock transformations are less profound; the action is not so deep-seated; but folding took place again on a large scale.

IV. Much later than this time, somewhere in the Mesozoic Era, probably in the Jurassic period, a fourth deformation, producing relief of mountainous character, was initiated. This one differed materially from the others preceding. The period of complex intimate injection was past; the period of maximum deep-seated batholithic invasion was over, and the period of great complex outbreaks had come to a close. Perhaps on this account or on some other not so easily distinguished, the new form of deformation was strikingly different. Block-faulting was developed on a magnificent scale. It was accompanied by accumulation of deposits in the troughs between the blocks, producing extraordinary thickness of conglomerate and coarse sandstones of Mesozoic age.

Although there was *no marked folding accompanying these displacements*, there was in places enough crowding of the fault-blocks to cause *local warping and folding*. Thus there is a kind of connecting link between the orogenic character of this period and that preceding. The capacity of the region,

however, for large scale folding had been lost, and in its place came localized weaknesses and isostatic disturbances that resulted in tilted blocks of great dimensions and of mountain-like relief.

In time the region attained enough stability so that erosion, which at first produced the thousands of feet of conglomerates and sandstones that belong to this period, finally spent itself in extensive peneplanation. Thus the Mongolian Peneplane was developed, which to this day is preserved as the floor on which the so-called Later Sediments lie. The volcanism of this period is still more simple than the preceding. There were volcanic outbreaks, but there was little effect produced on the earlier rocks and there was no intimate injection by them.

V. Since that time the history in every respect has been still more simple and such deformation as has been recorded in mountainous relief is either of simple block-faulting type or simple warping. Both types are represented in the Gobi region, on both large and small scale, with apparently no very different meaning. The forces accountable for both forms are directly beneath and of isostatic nature, probably connecting directly with continued deep-seated and local volcanism.

The most striking examples of the deformation of this time, which includes the time from the Cretaceous Period to the present, are the Altai Mountains in the central Gobi region with associated ranges, both large and small, on either side; and the Khangai range on the northern border of the Gobi, forming a portion of the Arctic Divide. The latter, as far as post-Cretaceous history is concerned, is structurally a broad uplifted arch that has been deeply dissected by erosion so that it has mountainous relief and rugged topography. It is made up of the ancient floor rocks with all of the complexities that belong to those systems, and, on this account, its history may easily be misread to greater complexity than it deserves. Its physiographic features, however, and its relation to the other elements of this interior basin indicate clearly that the present relief, so far as deformation and orogenesis in the strictest sense are concerned, is simply the result of gentle upwarping.

The Altai ranges[1] and their relatives are strikingly different in one respect. Each range is an uplifted and tilted fault-block which has raised the Oldrock floor high above the sediments on the disrupted basement. These blocks have been subjected to erosion which has given them considerable relief detail. In some cases nearly all traces of the original form has been destroyed, but in others, even the highest ones, such as Baga Bogdo of the Altais, which stands no less than 7000 ft. above the sediments of the adjacent plain, and Ikhe Bogdo which rises almost 2000 ft. higher, one can find complete proof of fault-block origin in late geologic time. One can trace the Mongolian Peneplane of the uplifted floor, and, in the case of Ikhe Bogdo, even remnants of the Later Sediments uplifted with it can be seen high over the flanks of the mountain.

Deformation of this kind has continued to the present day. Evidence of faulting and warping are detected in deposits of late Pleistocene age. This type has been accompanied by volcanism also, but of a still simpler character, represented by isolated volcanic vents with outpourings of lava and the development of ash and tuff, all of which are incorporated as members in the sediments. There are no injection phenomena. There is no marked modification of overlying strata. The volcanic phenomena, however, serve to indicate that beneath these blocks recording the faulting and warping of the present surface there is igneous activity of some kind.

In general, the series or succession of orogenic structures is strikingly simple and orderly, so orderly indeed that it leads one to speculate on their genetic relationship. They seem to represent a systematic and inter-dependent genesis. The changes from the beginning to the end are towards greater and greater simplicity, as if the violence and wide range of earlier movements were gradually changing to milder form and more localized disturbances.

Volcanism is the one feature that accompanied all of them, but the volcanism of the earliest orogenic period is a strikingly more vigorous and important matter in pro-

[1] These Altai ranges are those of Mongolia, and do not belong to the Altaids of Suess.—Ed.

ducing rock transformation than the later ones. With each successive orogenic period the effect of igneous activity is less pronounced on the rocks of the roof and the deformation as a whole is of a simpler type.

This very plain correspondence leads one to wonder whether volcanism may not be the most important factor in the whole history. It may be that the development of a great batholithic mass beneath is recorded from time to time in different deformation types. The earliest period is characterized by igneous injection and absorption of the original rocks, and marks early increasing deep-seated igneous activity. The second is characterized by little change of the overlying rocks but extensive, comparatively simple folding and enormous development of the batholith to maximum areal extent. The third is characterized by folding with abundant volcanic intrusions and many outbreaks of great petrographic variety. This stage marks the extreme of magmatic differentiation. The fourth is characterized by enormous block-faulting and simpler volcanism. And the closing type is characterized by simple warping and simple block-faulting with no effect whatever produced on the rocks of that time by volcanism, except that belonging to superficial outbreaks.

The series is essentially complete. Whether or not there s as simple a genetic relation as the series appears to have, may be impossible to prove; but the exhibit is a very remarkable one and well worth considering for its progressive character and for the close correspondence between decreasing igneous complexity and certain orogenic and structural changes. There are few regions of the world so well suited to this kind of comparison.

CHAPTER VIII

THE IMPORTANCE OF HORIZONTAL MOVEMENTS IN THE EAST INDIAN ISLANDS

By Prof. H. A. Brouwer, Delft.

Abstract by W. J. M'Callien, B.Sc.

In the Eastern Archipelago the mountains are of two ages—an older phase governed by erosion and a newer phase just appearing at the present day. Earthquakes show that movement is taking place now along certain definite lines in definite regions, whereas other regions (the western part except the region which is bounded by the Indian Ocean) are stable. The same story as is told by earthquakes is told by upheaved coral reefs on all the islands. Those islands, which have an altitude from the bottom of the sea of not much less than 30,000 ft., are higher than the Himalaya. The old mountain chains diverge in many parts of the Archipelago, such as at the north-western corner of Sumatra and in the north-eastern corner of Borneo. The Kainozoic strikes of these mountains cut through the directions of the present rows of islands and sometimes at high angles. These strikes therefore do not coincide with the coasts of many of the islands. The rows of islands clearly show the present movement because erosion did not yet affect them strongly, and their movement is clearly demonstrated by the characteristics of the upheaved coral reefs.

In the rows of islands and the troughs between we see groups of anticlines and synclines. Sometimes a stage of two rows of islands, corresponding to two anticlines with a syncline between, is followed by a stage in which there is only one row

of islands. This arrangement is due to the fact that contrary to the general conception horizontal movement at the present time is often much more important than vertical movement. The latter, however, is the type of movement which affects topography most.

The coral islands are in the form of pitching geanticlines and the straits between the islands are caused by a transverse fracture along a bend in the geanticline axis. This bend is formed by a difference in horizontal movement.

POSTSCRIPT TO CHAPTER III

1. p. 69. To footnote add : Permo-Carboniferous and Jurassic fossils were found by Dr. de Böckh and his party in the Kuh-i-Gakum-Furgun trend, also in front of overthrust folds. The Paleozoic and Lower Mesozoic thickness is about 6500 ft., and the Cretaceous and Kainozoic 20,000 ft. These discoveries indicate that Paleozoic and early Mesozoic may be expected in the autochthonous folded zone.
2. p. 95. Dr. Lees and party have found extensive Lower and Middle Eocene red beds between Mahidasht and Chadavur. They are in places 2000 ft. Locally a red bed occurs in the Maastrichtian.
3. p. 99. Dr. de Böckh, K. W. Gray, and V. Boileau found in Puh-i-Pashkand (79 miles N.W. of Bandar Abbas) a 550-ft. limestone series with reticulate Upper Eocene nummulites (*N. gassinensis* Prever and *N. fabiani* Prever).
4. p. 105. The investigations of 1928-29 show that the Middle Fars fossils are mostly facies forms, which explains the difficulty of their correlation with the Chake Chake Beds of Pemba. *Cf.* Douglas, *Contrib. Pers. Pal.*, Pt. III.
5. p. 121. The Aoroman Range (the continuation of the Kuh-i-Parao at Kermanshah) was found by Messrs. Lees and Bleeck to consist at Han-i-Guermela, N.E. of Halabja, of Triassic limestones with *Megalodon*, *Myophoria* and crinoids. The limestones underlie red cherts and limestones, over which is an unconformable and infolded conglomeratic hippuritic limestone.
6. p. 135. The survey in 1928-29 has given no evidence of the connection of the basic igneous rocks and the radiolarites, which with the accompanying grits and conglomerates overlap an older floor and are penetrated, as are also the Cretaceous, by the igneous rocks.
7. p. 138. The so-called plant-bearing series has a wide extension. De Böckh, K. W. Gray and V. Boileau found, to the S.W. and W. of Bidishk (Lat. 28° 55′, Long. 56° 11′) about 10,000 to 11,000 ft. of beds which contain plant remains at their base. Towards Agark or Agirq they pass into limestones with small *Orbitolina*.
8. p. 148. The oldest transgressive rocks in the Oman folded zone are Maastrichtian. The movement may be Senonian as in the Zagros. Transgressive and uncomformable Cenomanian is known only in the foreland at Dhofar.
9. p. 157. Since writing the above (see footnotes on pp. 69, 85 and 138) graptolites have been found in the Gakum-Furgun trend, and also Permo-Carboniferous and Jurassic. Dr. Lees found Triassic and Jurassic in the Zimkan valley and in the Aoroman mountains, but from the character and fauna of these rocks it seems that there have been big older masses separating the northern and southern areas. The Cretaceous in the napped zone is in many places transgressive over older rocks.

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